Modeling 3D Scenes

Paradigm Shifts in Photogrammetry, Remote Sensing and Computer Vision

Reinhard Klette
CITR, The University of Auckland, Auckland, New Zealand

Ralf Reulke
Humboldt University and DLR, Berlin, Germany

Paradigm

1962: "...a constellation of concepts, values,
perceptions and practices
shared by a community
which forms a particular vision of reality
that is the basis of the way
a community organises itself."

T.S.Kuhn. *The Structure of Scientific Revolutions.* BGSU, 1962

Contents of Talk

Progress in digital frame cameras

- the basic tool

Computer vision

- success stories in 3D object modeling

A few words on laser range finders

- new opportunities for 3D scene modeling

Photogrammetry and remote sensing

- from digital frame cameras to line cameras

Panoramic imaging

- by applying line cameras

Unified applications of new technologies

- example: LRF and line camera for 3D modeling

Conclusions

Properties of Interest

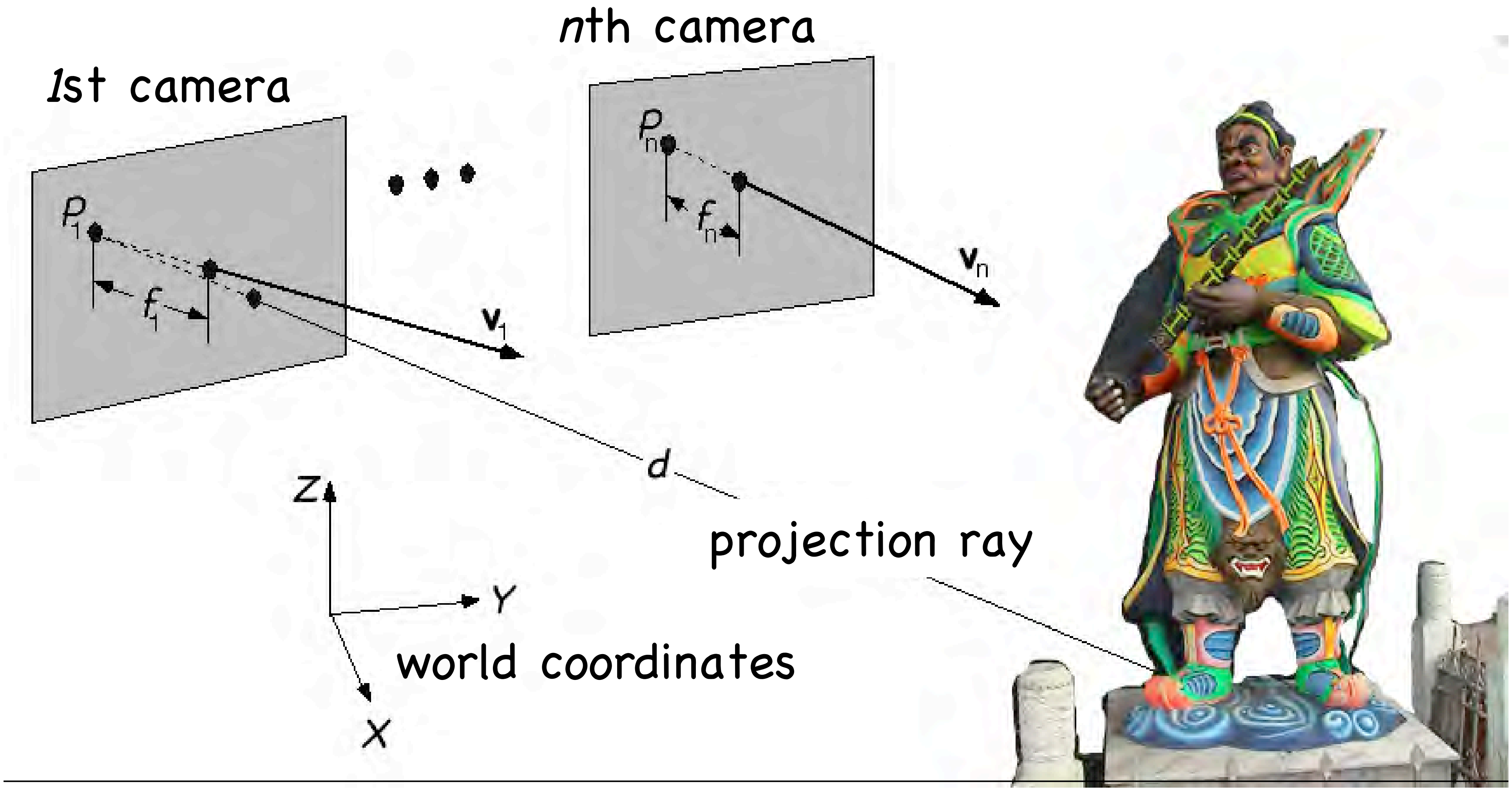
3D scene properties
Distances between camera and objects in the scene
Color textures of object surfaces

Changes in 3D scenes
Varying lighting conditions, weather, etc.
Coping with dynamic scenes

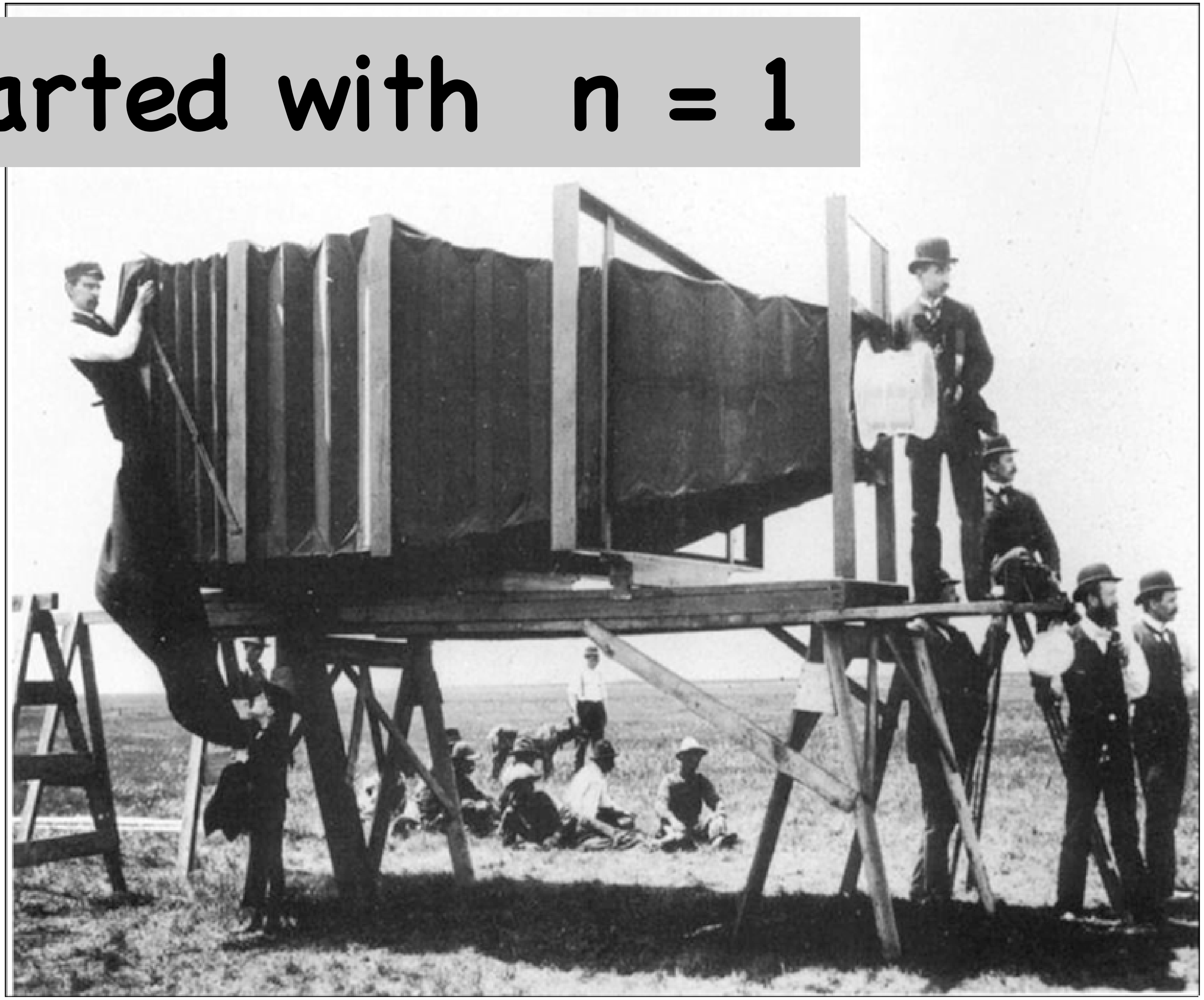
Calibration
Positions of cameras or used sensors (tools)
Viewing directions of cameras or sensors
Inner camera parameters

$n \geq 1$ pinhole cameras

(Still) the Common Default



it started with n = 1

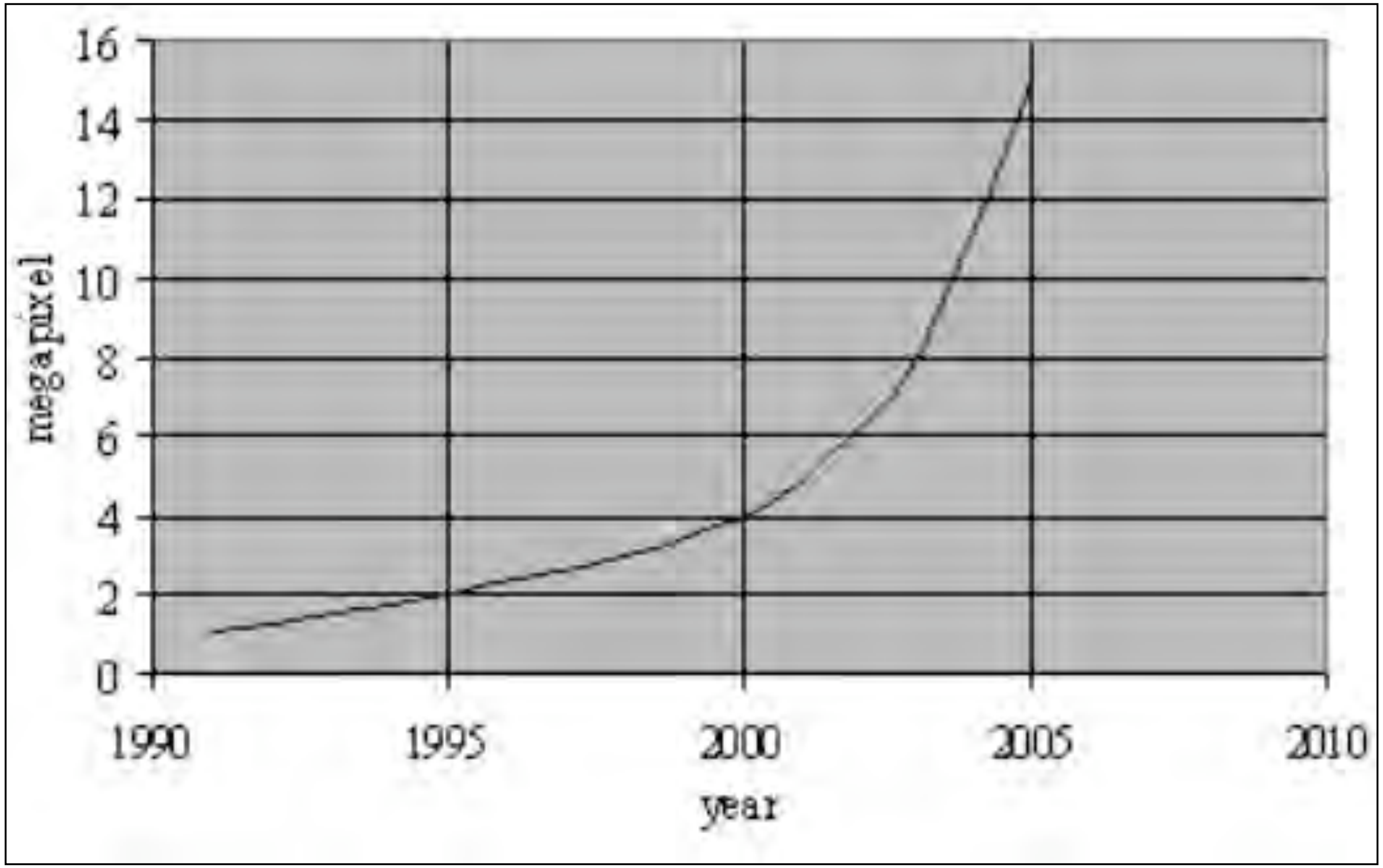


1900: The railroad camera of George R. Lawrence

Division of Photographic History, National Museum of American History, Smithsonian Institution

Digital Camera Technology

1951: video tape recorder for capturing live images
1960: NASA space probes send digital images
(e.g., from the moon)
NASA uses computers to enhance these images
1960: digital images used for spy satellites
and reconnaissance cameras
1972: patent for a film-less e-camera (Texas Instruments)
1981: commercial e-camera (still images, Sony Mavica)
1986: one-megapixel sensor (Kodak)
1990: photo CD (Kodak)
1991: digital camera for professional photographers (Kodak)



2005: resolution of small- or medium-format digital cameras

End of 2004: **CCD matrices**

Manufacturer	Model	Array	Photopixel
Kodak	KAF-16802CE	4k x 4k	16 Mpixel
Kodak	KAF-11000M	4k x 5.4k	22 Mpixel*
DALSA	FTF5066	5k x 6.6k	34 Mpixel
Philips/DALSA	FTF7040	7k x 4k	28 Mpixel
Fairchild	CCD595	9.2k x 9.2k	85 Mpixel

* Used in digital backs from Phase One, Leaf America, ...

Trends

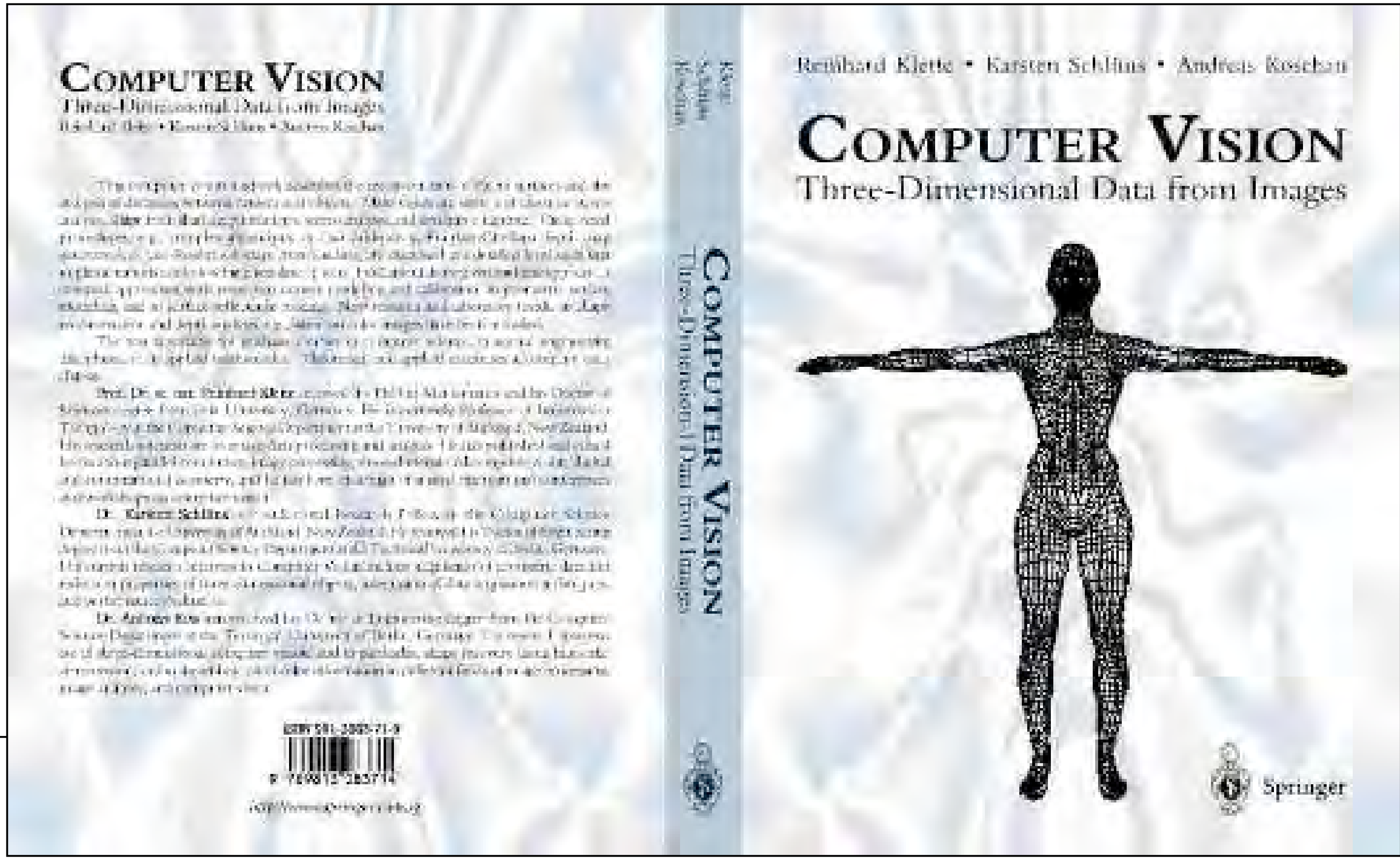
- High resolution matrices (> 100 MPixel) might be available in a few years from now
- **early 2004**: Commercial high resolution photo systems in a price range of up to €10k had 6 to 16 MPixel matrices (e.g., Kodak DCS Pro 14n and Cannon EOS-1Ds)
- „Killer applications" call for high-quality systems with more than 16 MPixel
  - airborne photogrammetry (remote sensing)

    (e.g., systems Z/I DMC, Vexel UltraCam, and Applanix/Emerge DSS)
  - medical applications
  - terrestrial photogrammetry (e.g., architecture, art)

Computer Vision

use cameras (and other sensors or tools) for modeling (and understanding) the 3D world

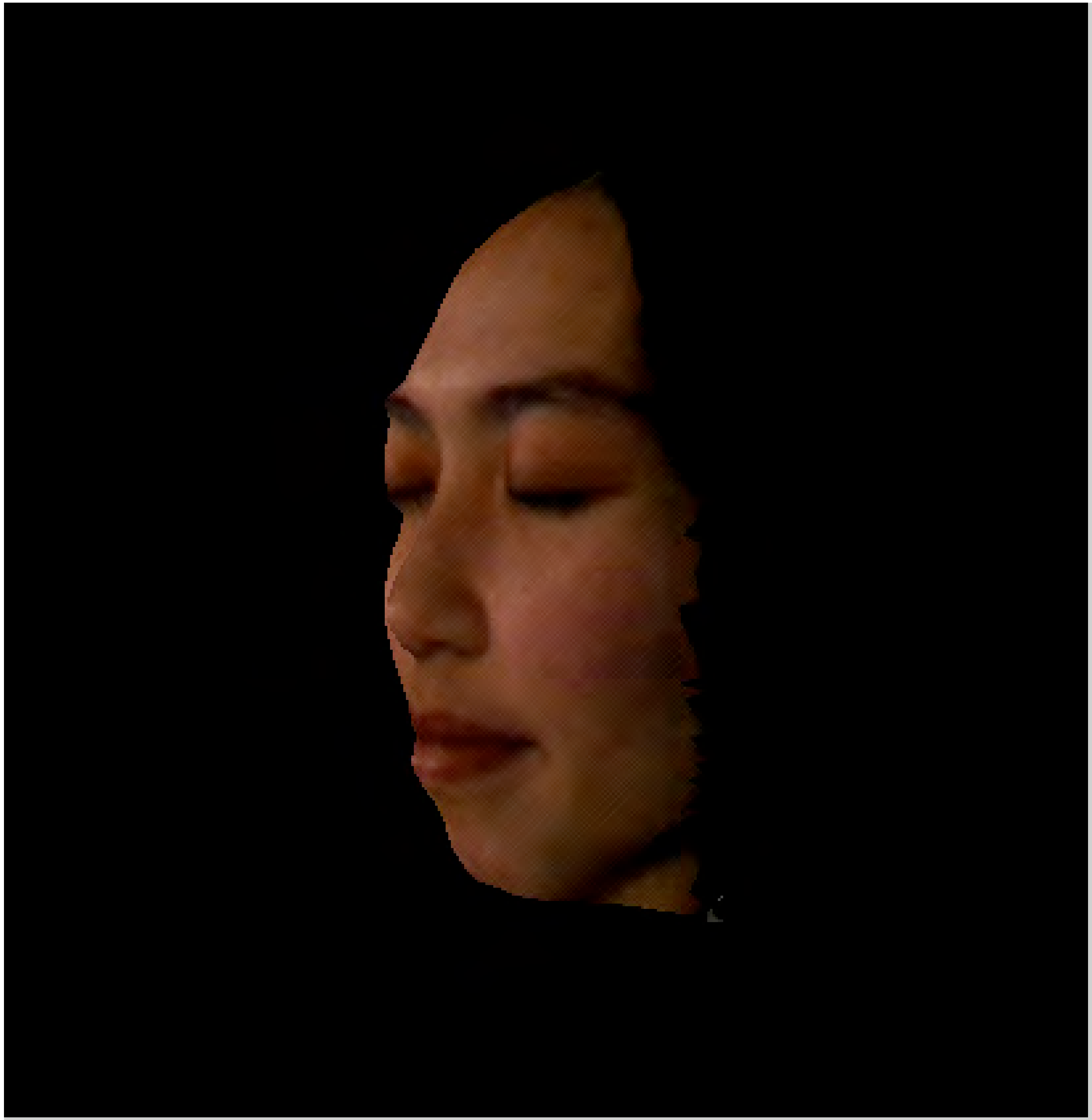
Example: 2.5D or 3D shape recovery



Photometric Stereo

Input: three pictures of a static object
same camera, but different light sources

Task: calculate 3D shape of object
calculate surface albedo (e.g., for MPEG 4)



method:

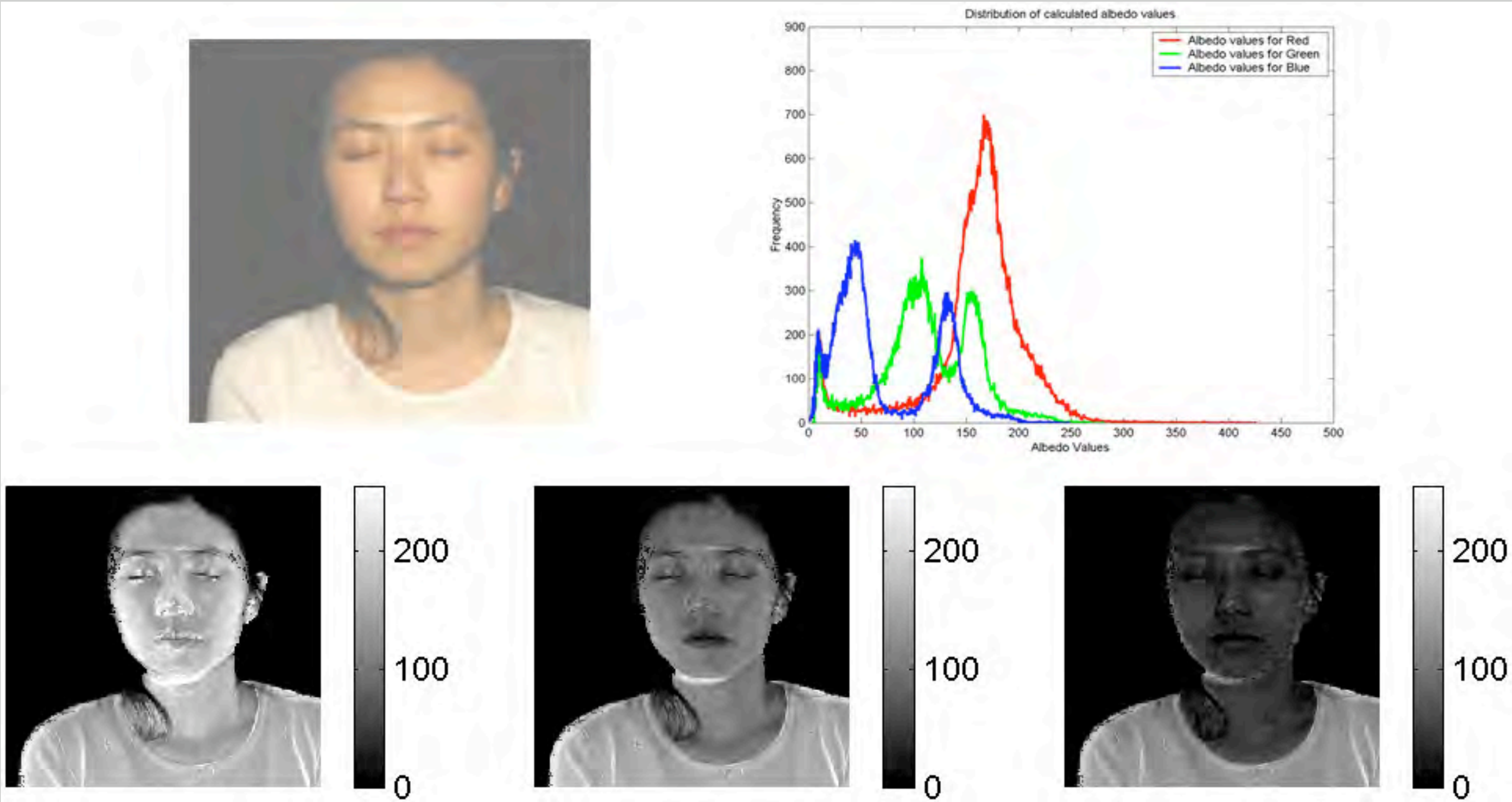
albedo-independent 3-source photometric stereo

1996: Klette, Koschan, Schlüns

applications to face modeling

1999: Chia-Yen Chen

2002: Distribution of calculated albedo values

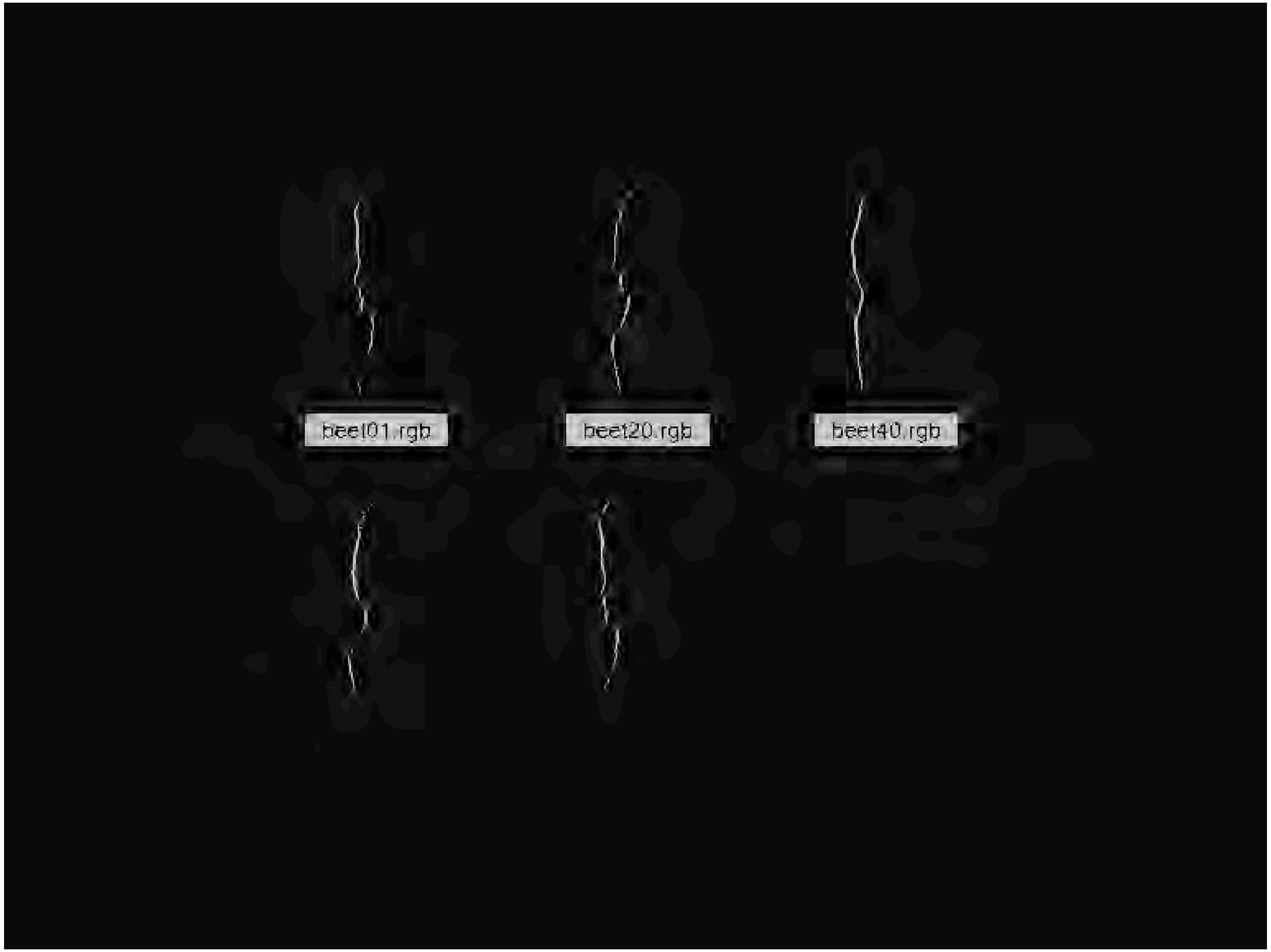


Red | Green | Blue

CITR (C.-Y. Chen, R. Klette) & Agilent Technologies (R. Kakarala)

1997: shape from silhouettes

1997: light plane projection (structured lighting)



Structure from Motion

Step 1: single stereo pair of images at two uncalibrated positions of camera

Step 2: corresponding points

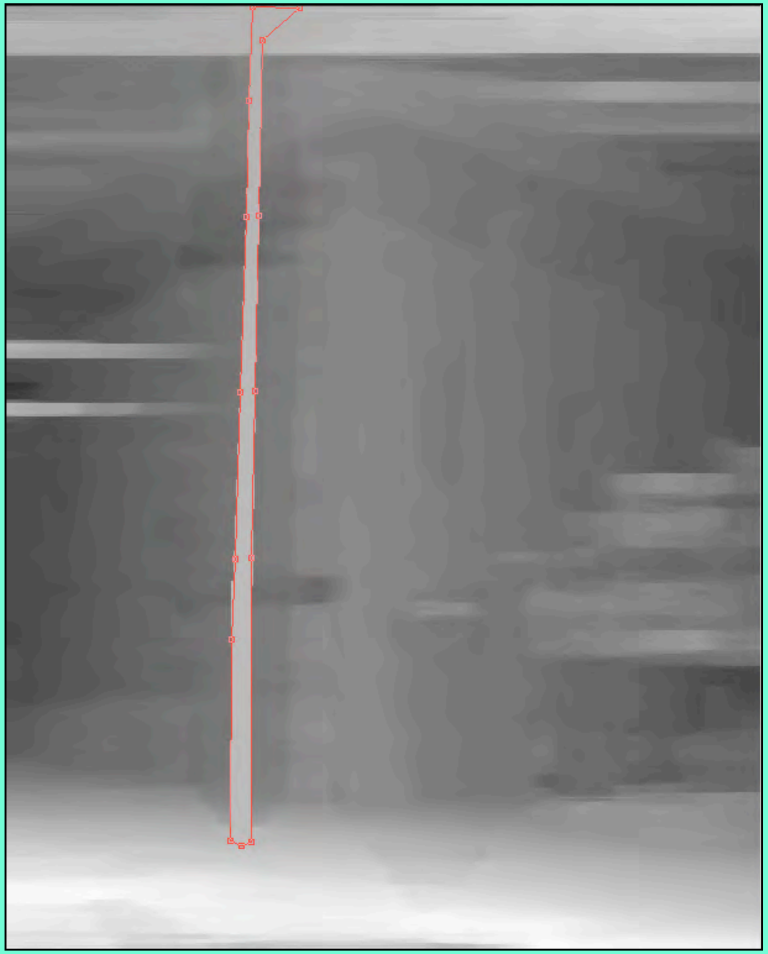
Step 3: fundamental matrix

Step 4: standard geometry

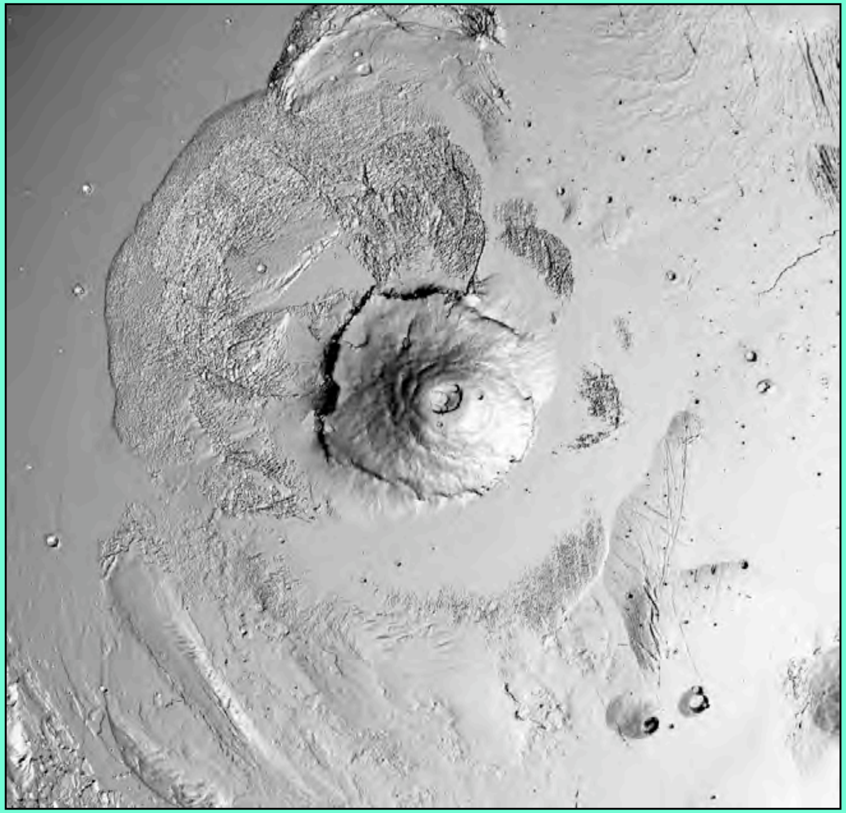
Step 5: digital surface model (DSM)

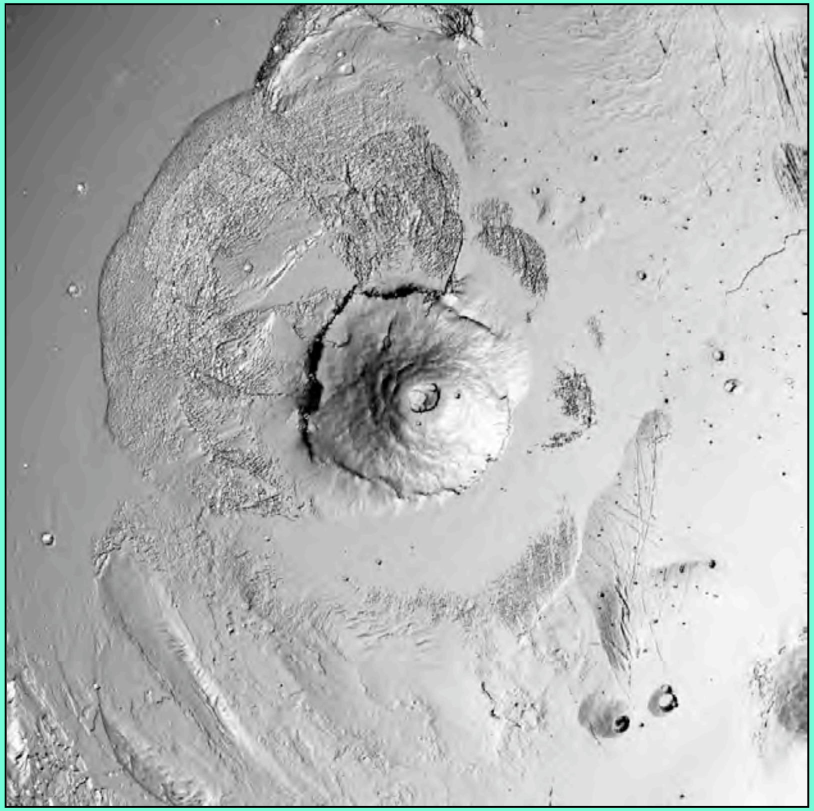
Step 6: 3D editing

Step 7: triangulation, masking, saving of individual objects



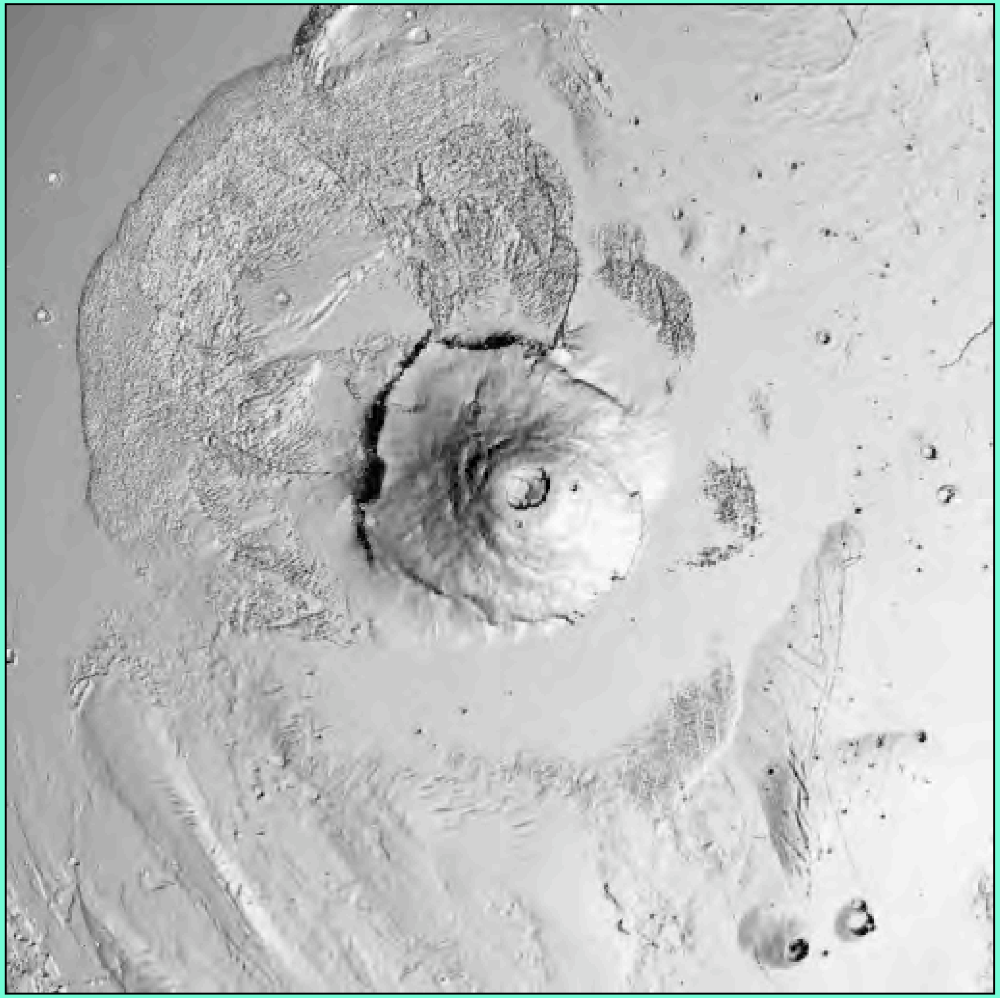
2004: animation “CITR building”
created from 2 images (and no further info)





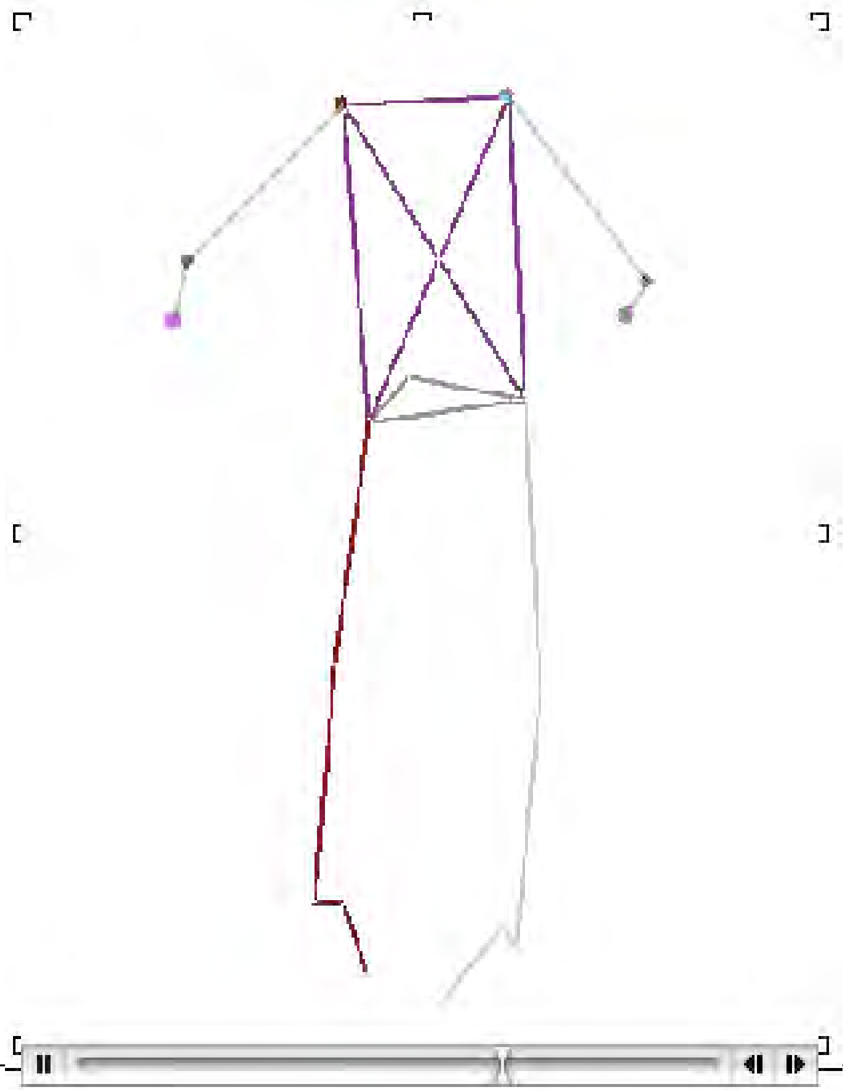
2003: Mons Olympus on Mars
2 images taken during the descent of the probe
at slightly different elevations

NASA



2004: animation “Flight around Mons Olympus”
created from these 2 images (and no further info)

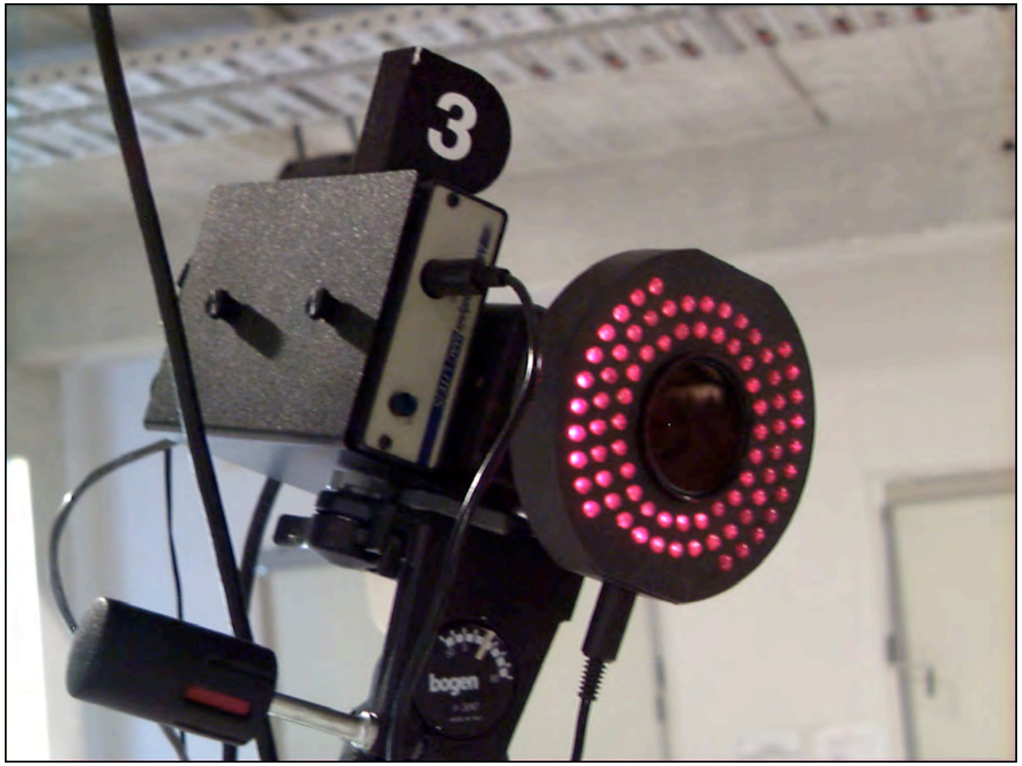
Modeling of Dynamic 3D Objects



RK_RR

2000: UoA, Sports Sciences

Fast Cameras and Strobe Lighting



2000: strobe lights around the optics are used to intensify the visibility of special light-reflective markers

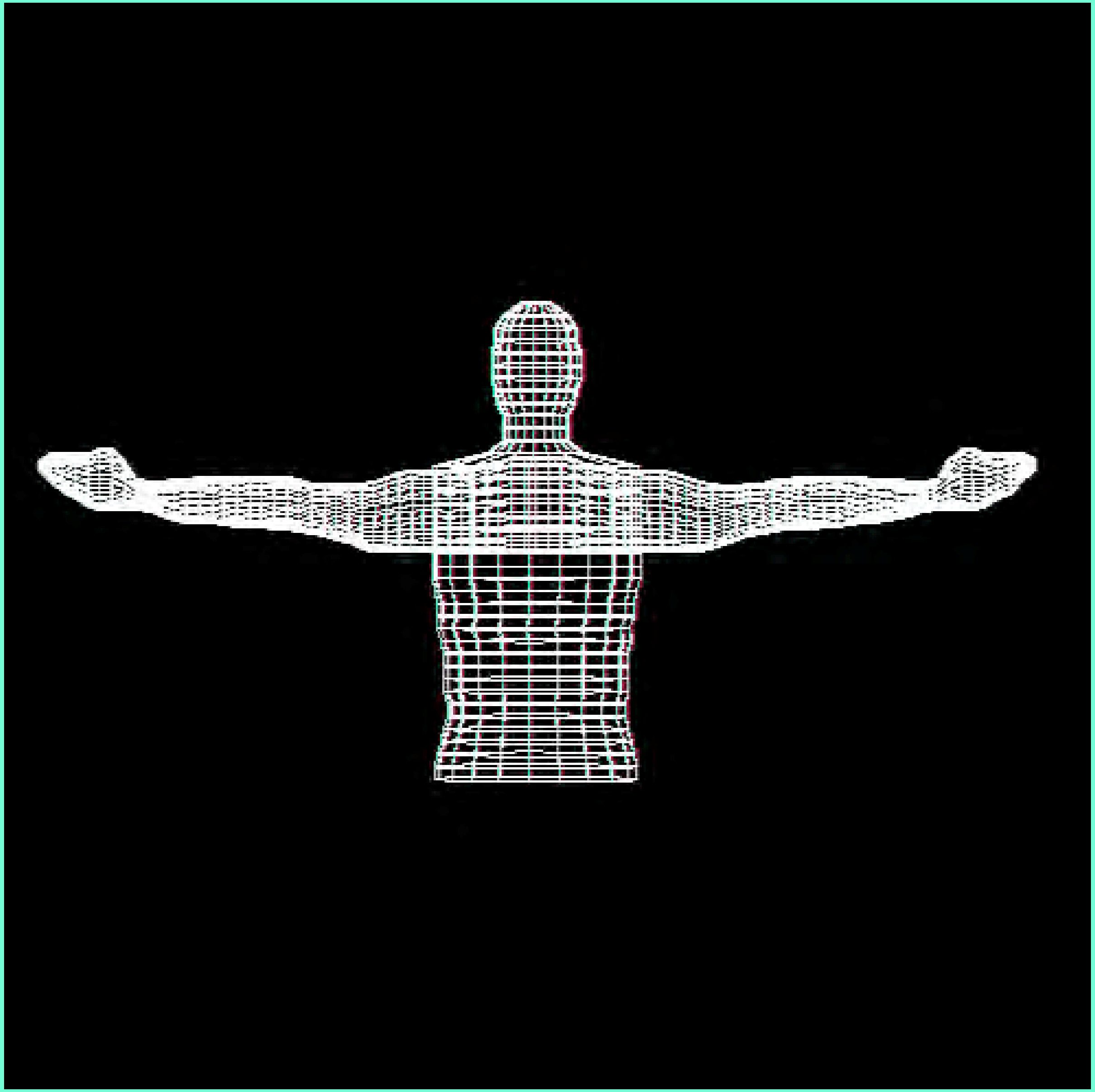
cameras and strobes are capable of capturing images at 240 Hz.

Strobe light = light that flashes to a predetermined frequency
Here: red strobe light flashes at the shutter speed of the cameras (60, 120, or 240 Hz), strobe lights of all cameras are synchronized

2004:

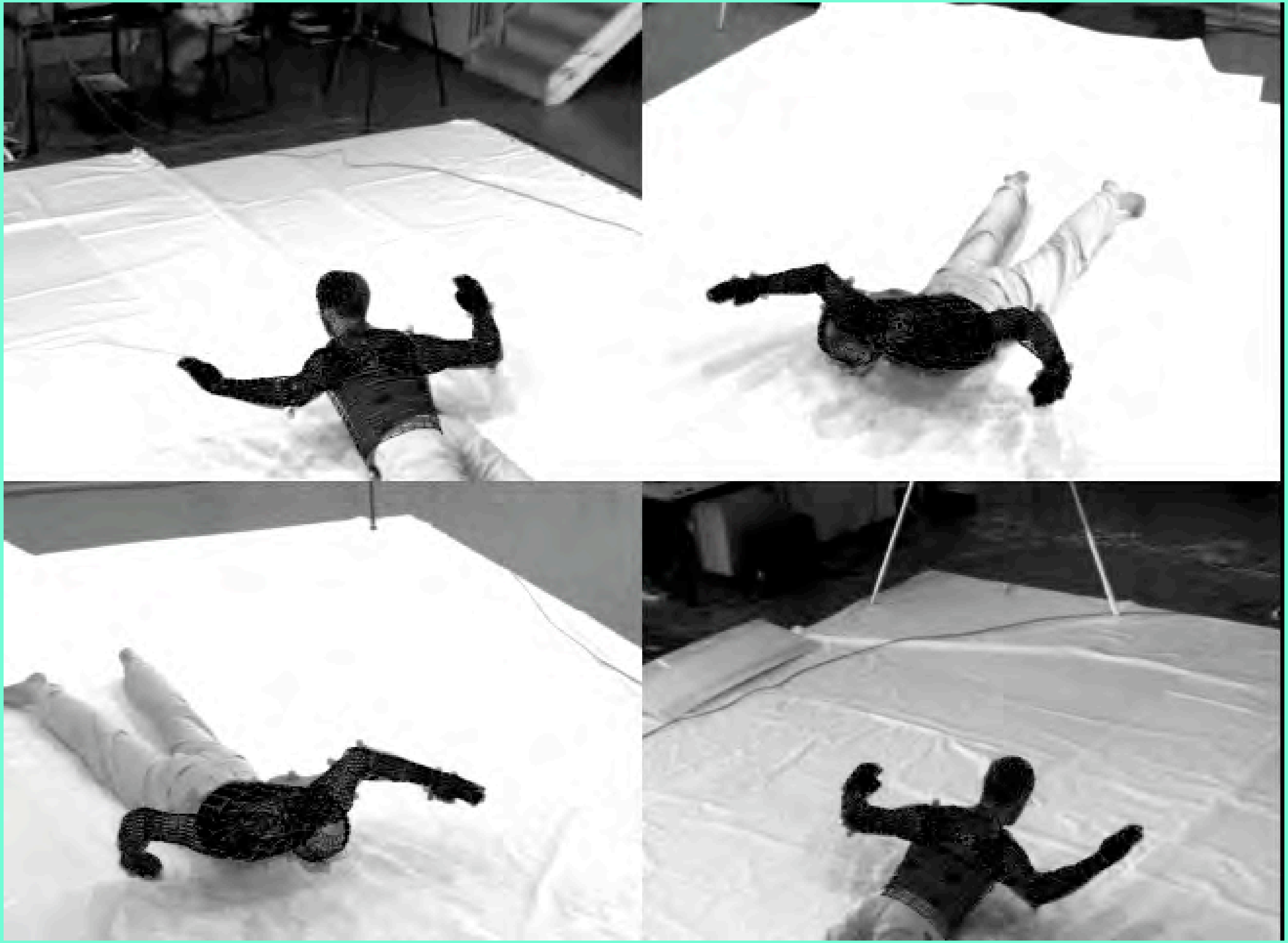
Pose Recognition

- marker less
- no strobes
- fast cameras

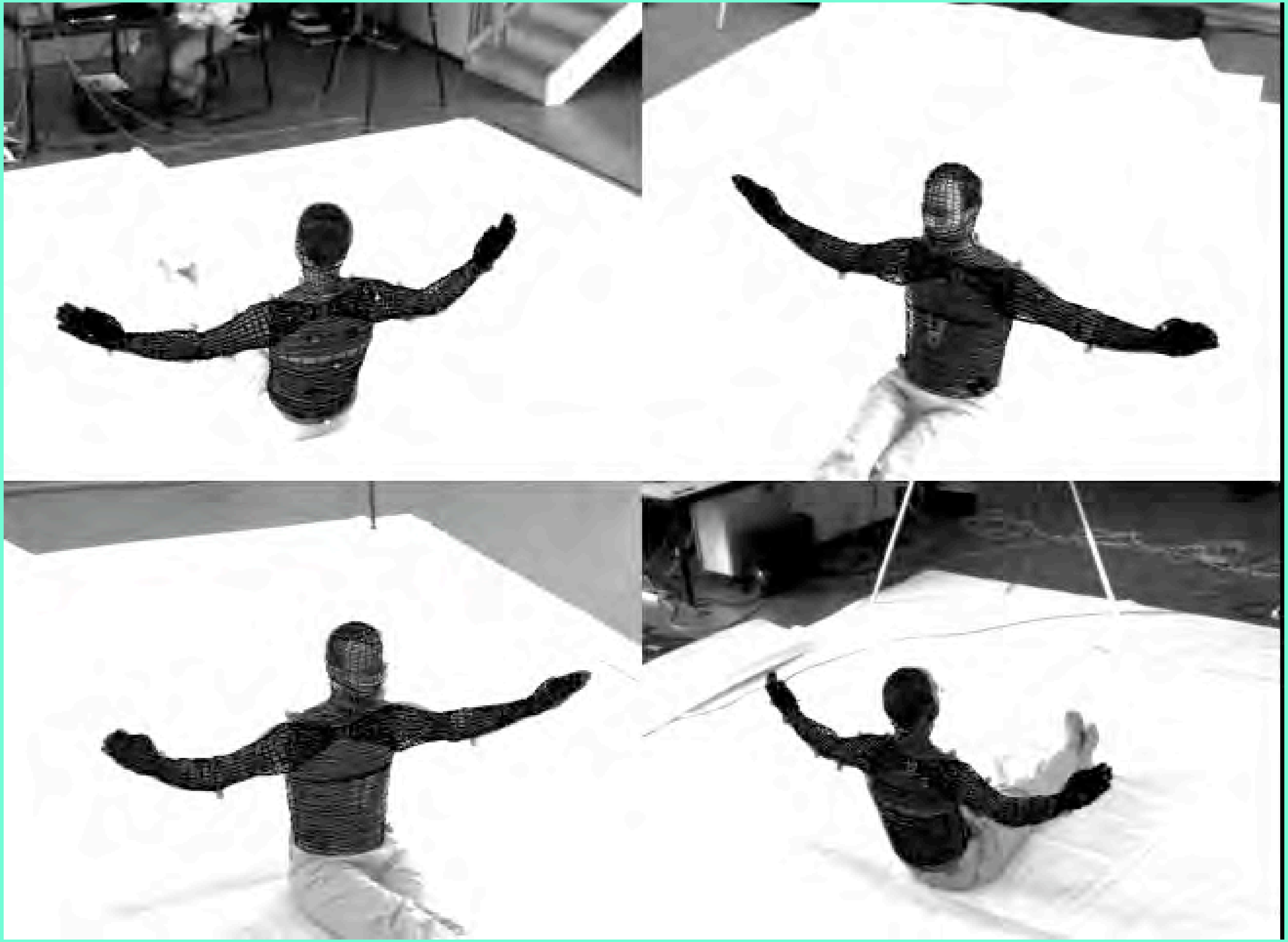


generic model of human body

Left to left etc. - also after occlusion

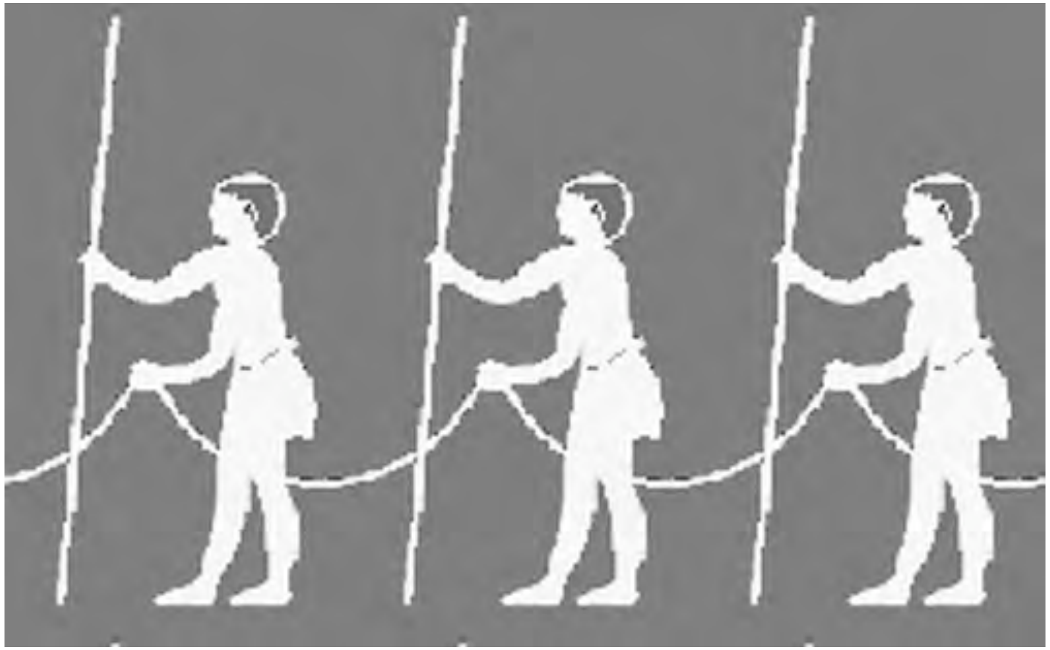


Position and motion of occluded body parts, 21 DoFs



Clipping, occlusion, and all 21 DoFs

Distance Measurement

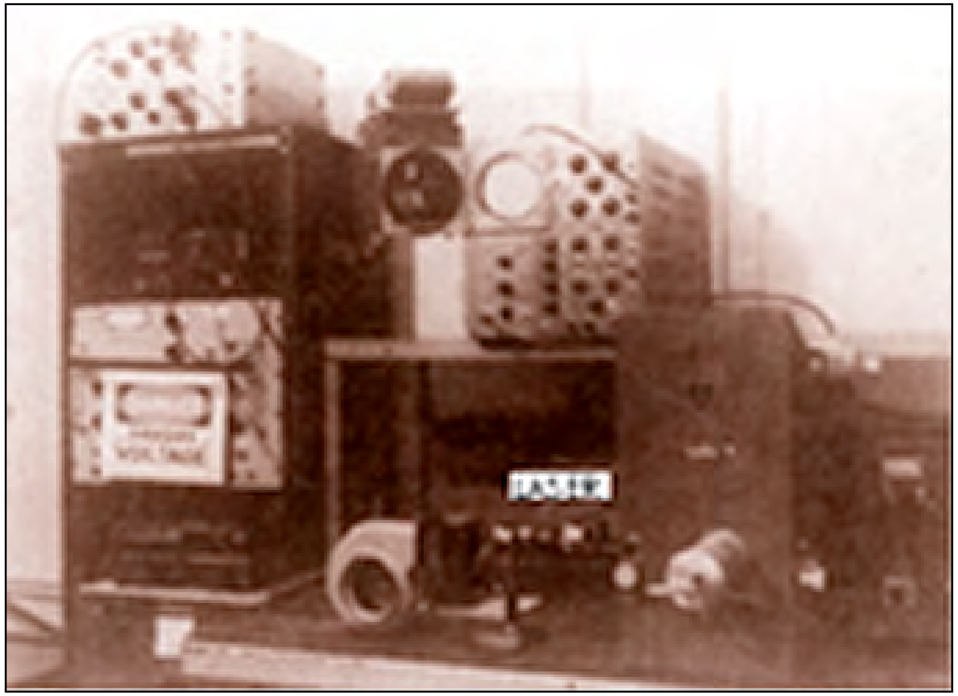


ancient Egyptian surveyors
(harpedonapata = “rope-stretcher”)

used ropes and knots, tied at pre-determined intervals, to measure distances

http://education.qld.gov.au/curriculum/area/maths/compass/html/surveying/suhis.html

Laser Range Finder



1960: original lab set-up
for the ruby laser

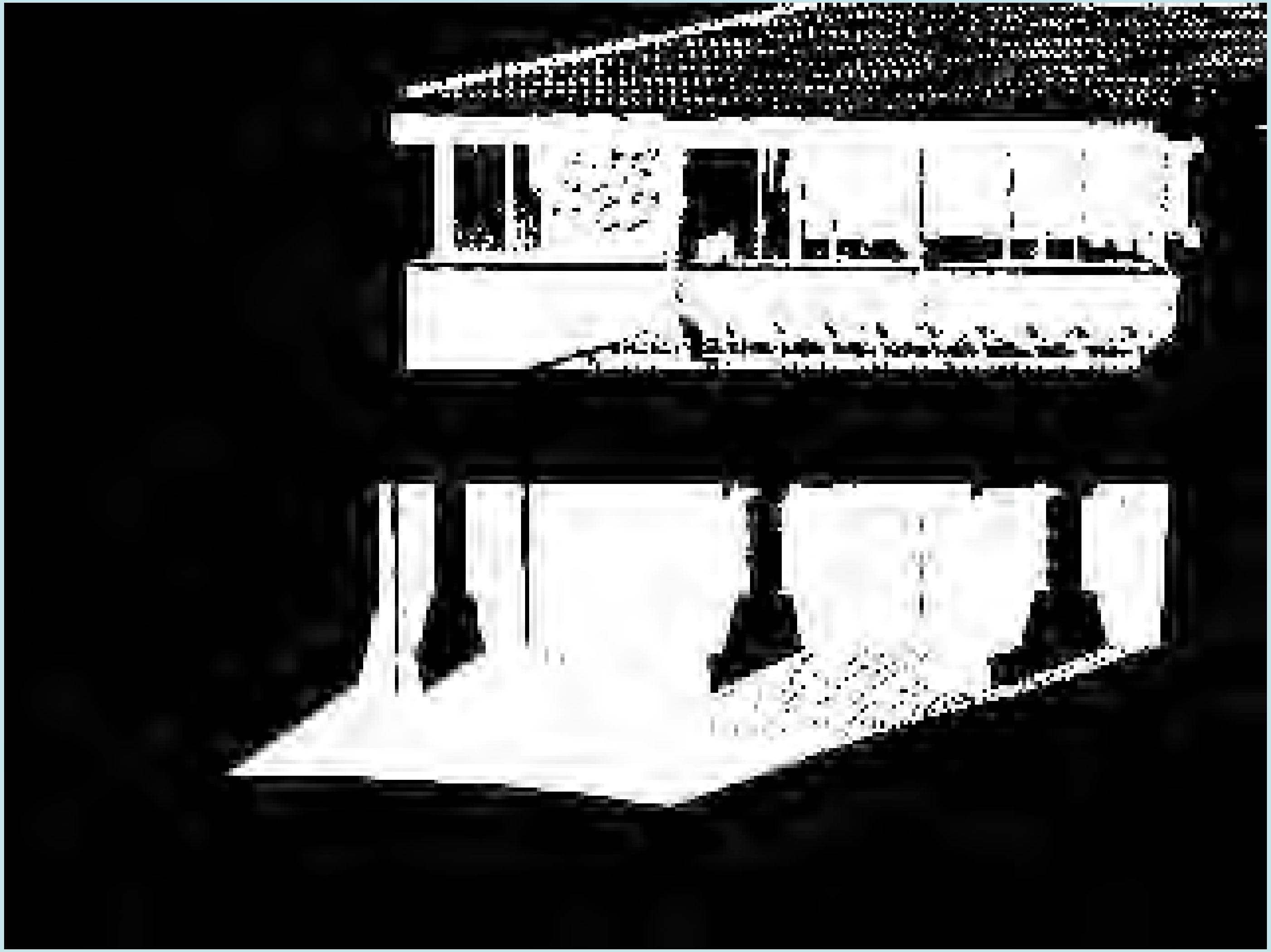
the *first laser range finder* (LRF):

it used ruby lasers and was demonstrated less than a year after the laser's discovery in **1960** at Hughes (time-of-flight LRFs)

2005: laser scanner Cyrax 2500

with build-in color camera

Animated raw data: cloud of 3D points, single viewpoint building of CITR, Tamaki campus



CITR (X. Zhang and K. Scheibe)

Phase-Difference LRFs

allow to measure accurate range values as well as intensity (gray) values.

example (data as by producer):

	LARA25200	LARA53500
Distance up to ...	25.2m	53.5m
Error in range data	< 3mm	< 5 mm
Data acquisition rate:	< 625 Mpx/sec.	< 500 Mpx/sec.
Laser output power (CW)	22 mW	32mW
Laser wavelength:	780 nm	
Beam divergence:	0.22 mrad	
Laser safety class:	3R (DIN EN 60825-1)	
Field of view vertical:	310°	
Field of view horizontal:	360°	

Zoller und Fröhlich GmbH, Wangen. Germany

2001: intensity data, castle Neuschwanstein, Bavaria, Germany
Leica HDS 4500

B. Strackenbrock and K. Scheibe, Berlin

Intensity data

DLR & CITR (K. Scheibe)

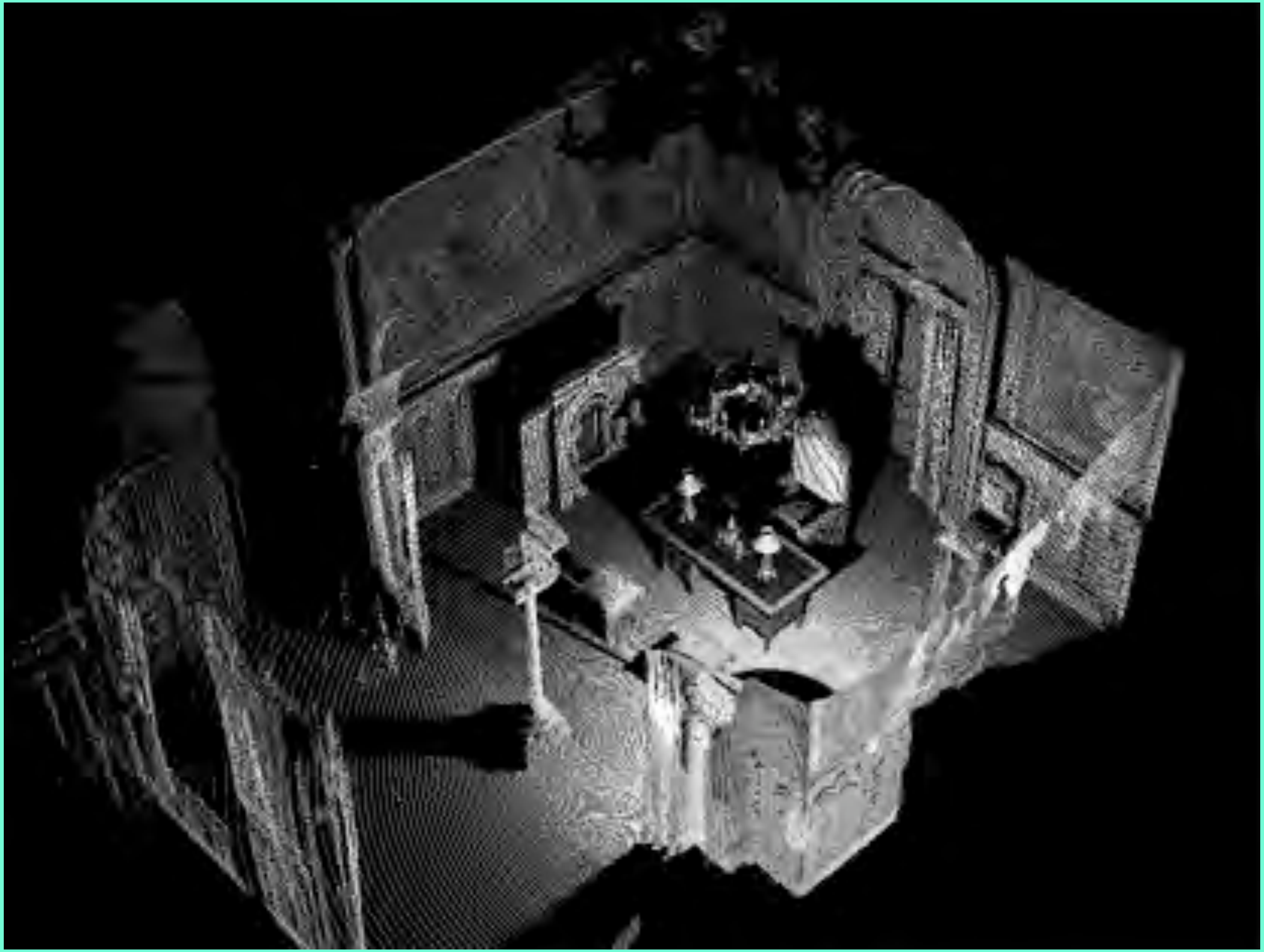
RK_RR

Range data

DLR & CITR (K. Scheibe)

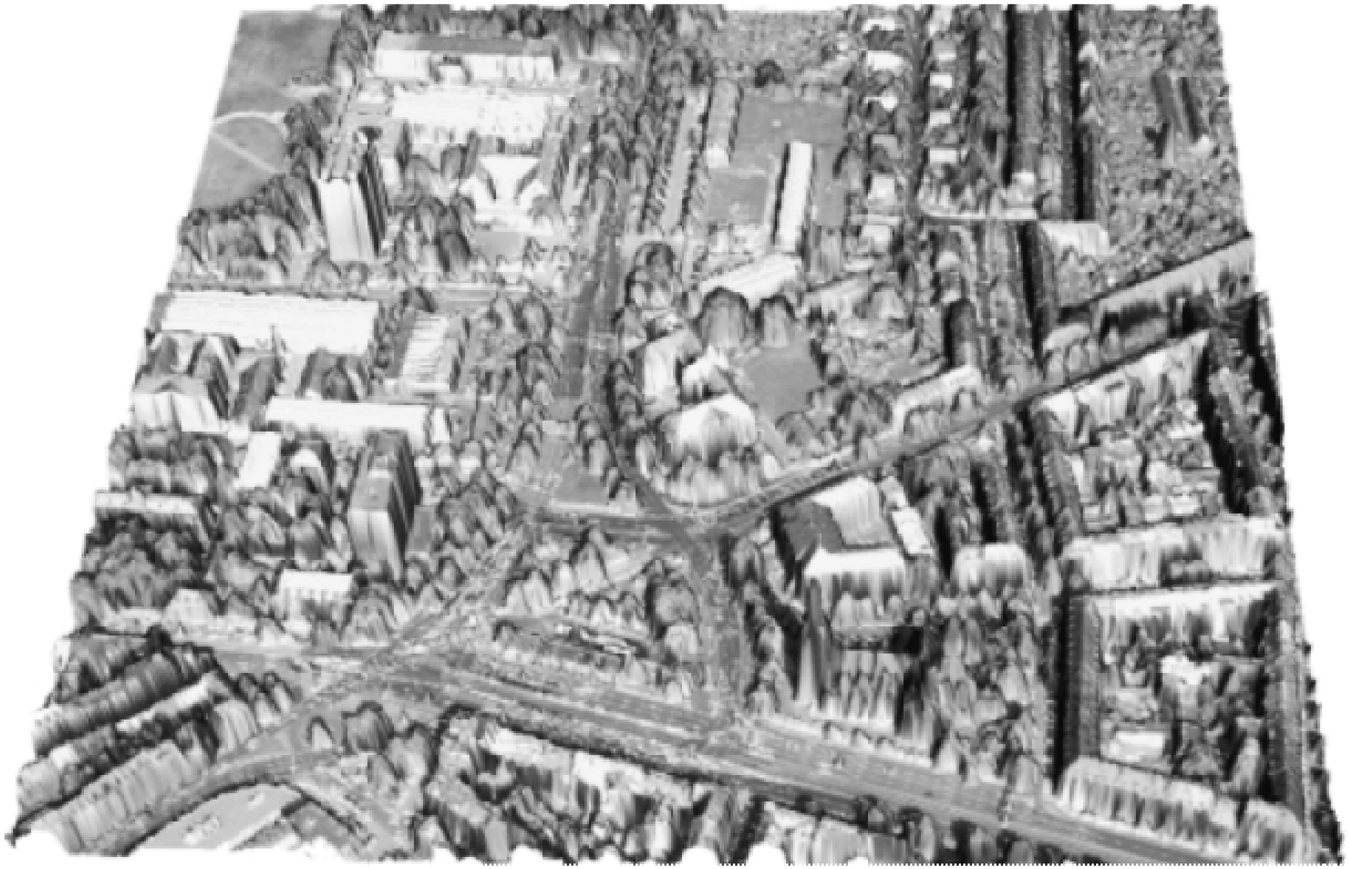
RK_RR

Office of King Ludwig in castle Neuschwanstein



DLR & CITR (K. Scheibe)

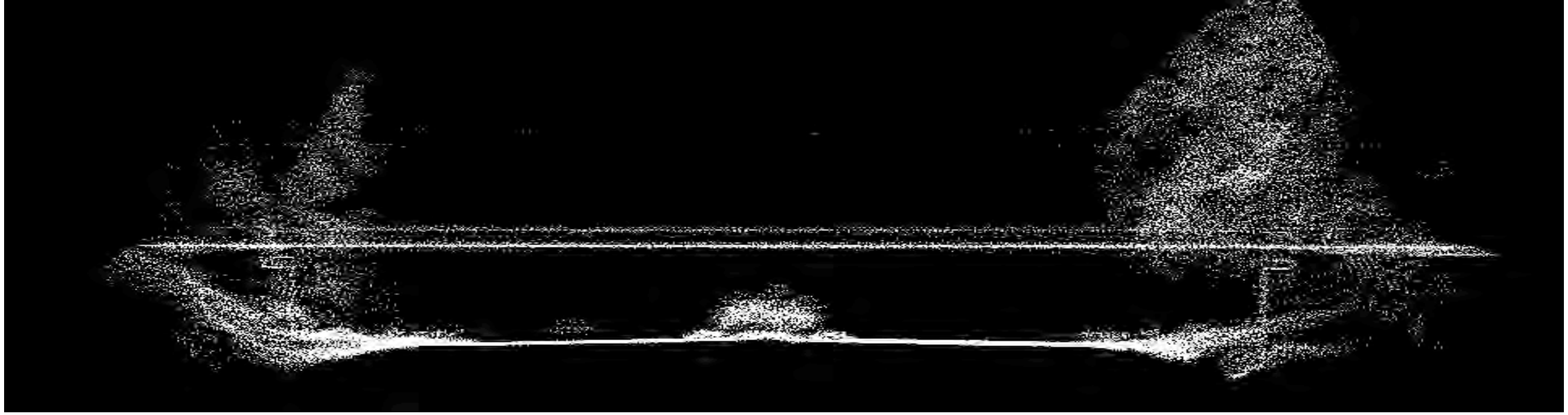
City Center Modeling



1999: Karlsruhe, laser range finder on airplane

U. Lohr, Karlsruhe

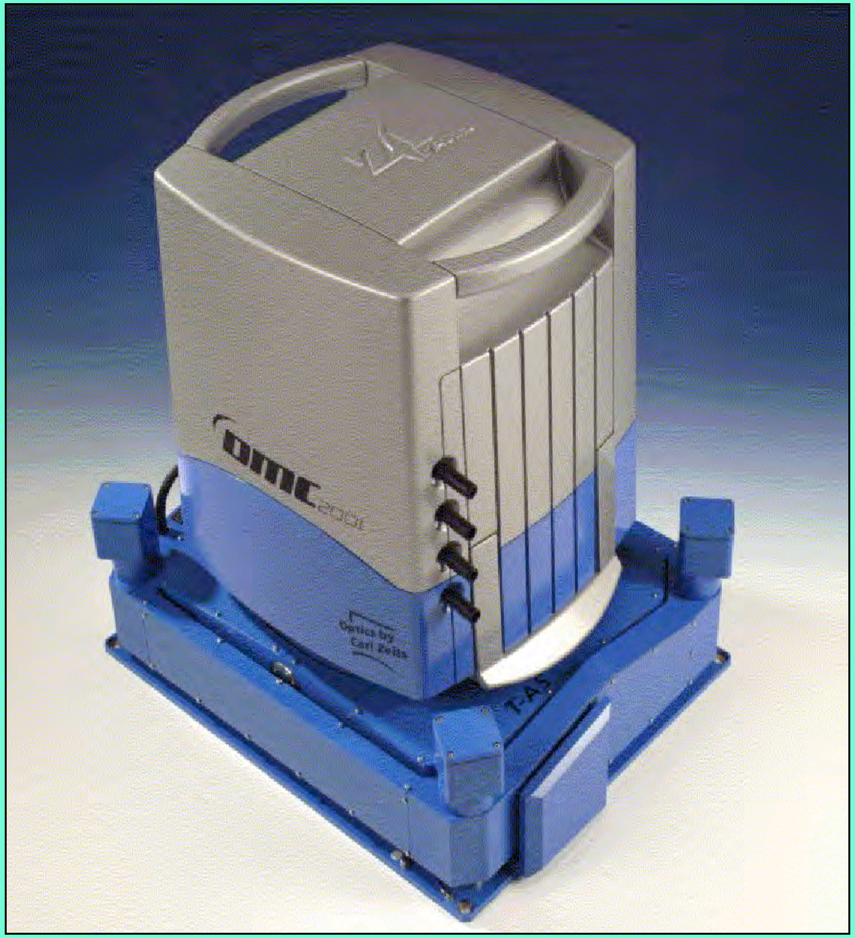
2004: elevation detection
of power lines (LRF on helicopter)



Aerial Photography, Remote Sensing, Photogrammetry

1906: San Francisco in ruins
aerial photograph by George R. Lawrence

http://www.rtpnet.org/robroy/lawrence/landscape.html



Digital Modular Camera (DMC)

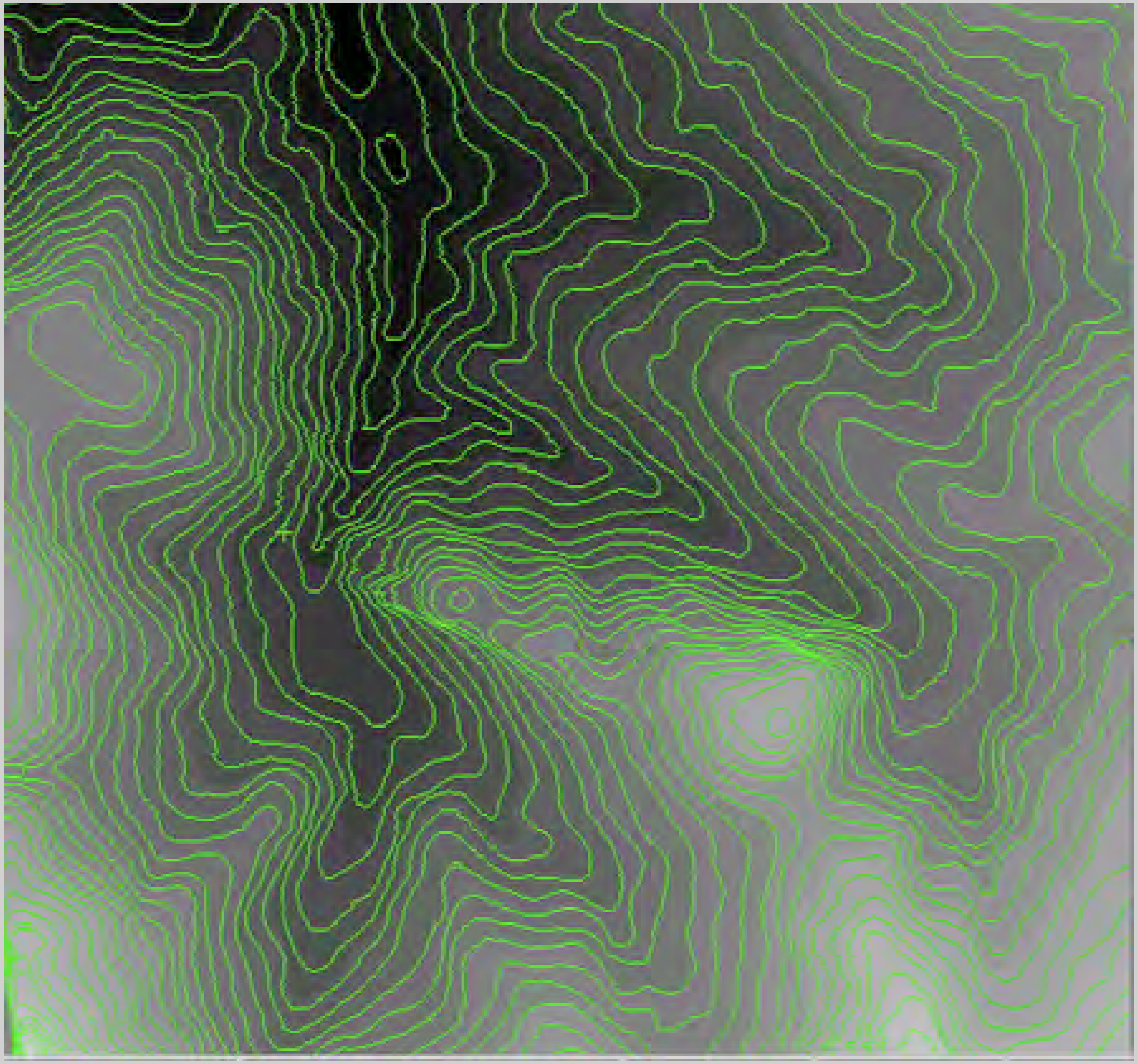
DMC2001
Digital Modular Camera
A Product of ZI Imaging

2001: 7k x 4k panchromatic images (4 CCD matrix cameras)
3k x 2k RGB images

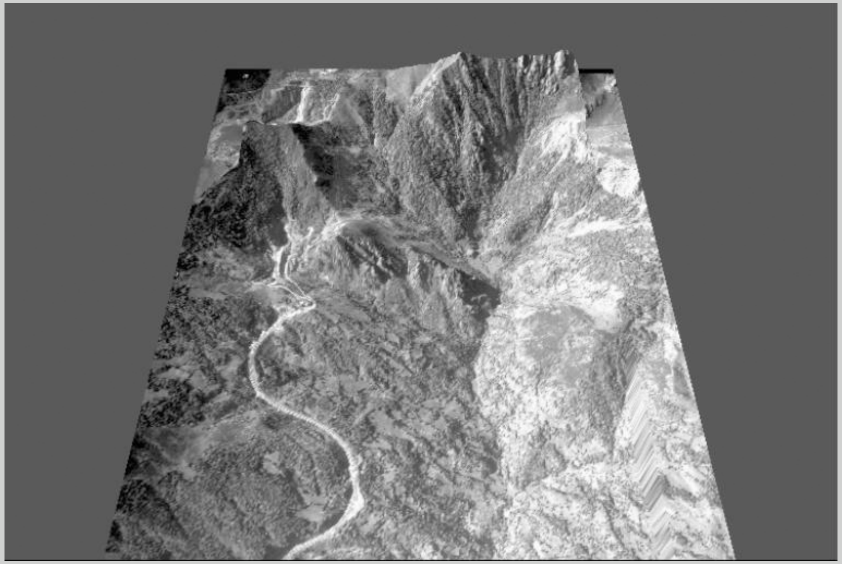
Intergraph - Carl Zeiss joint venture

Automated Stereo Analysis in Computer Vision

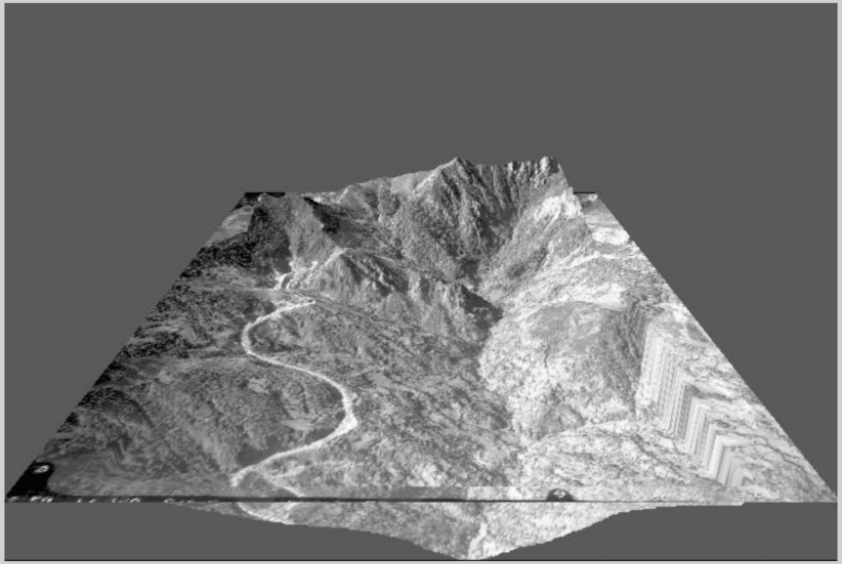
1997: mountains in Nepal
left and right image of a stereo pair

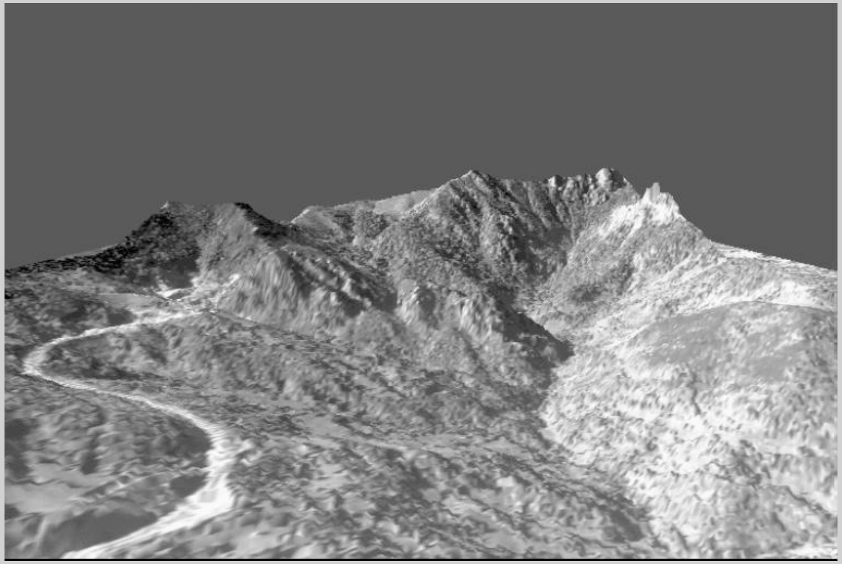


1997: automatic generation of DEM, illustrated by isolines



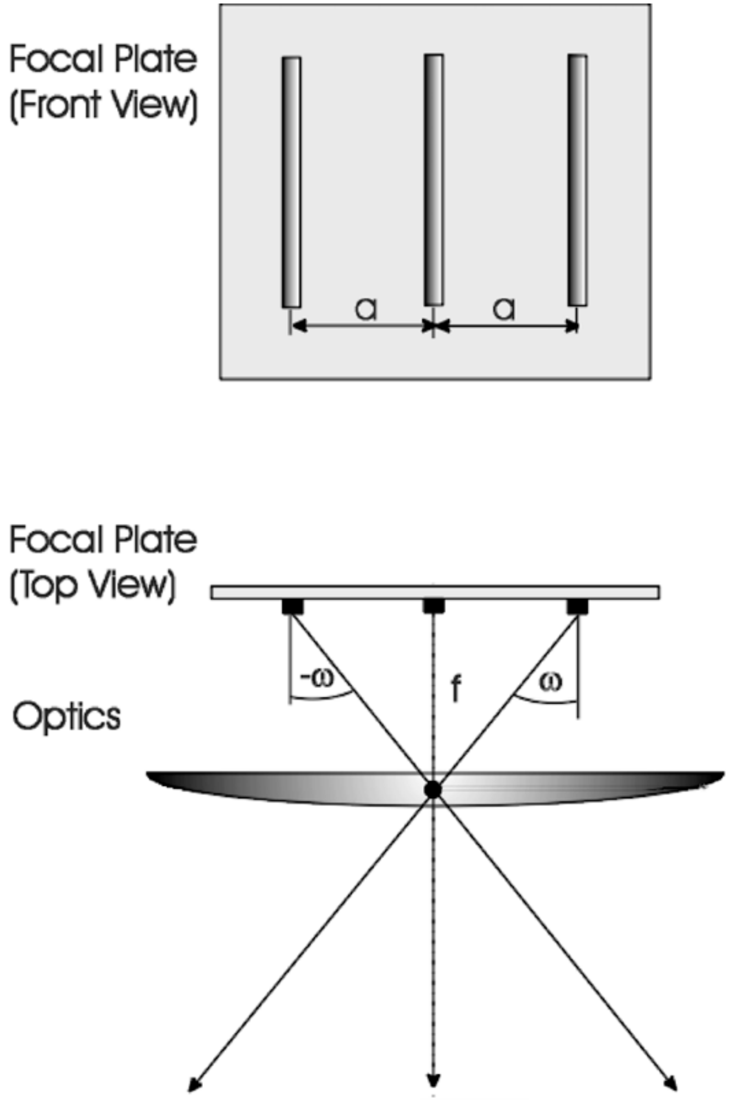
3D Animation of DEM





CITR (K. Schlüns and S.-Z. Zhou)

Digital Line Cameras for Remote Sensing



1998: WAAC (*Wide Angle Airborne Camera*)

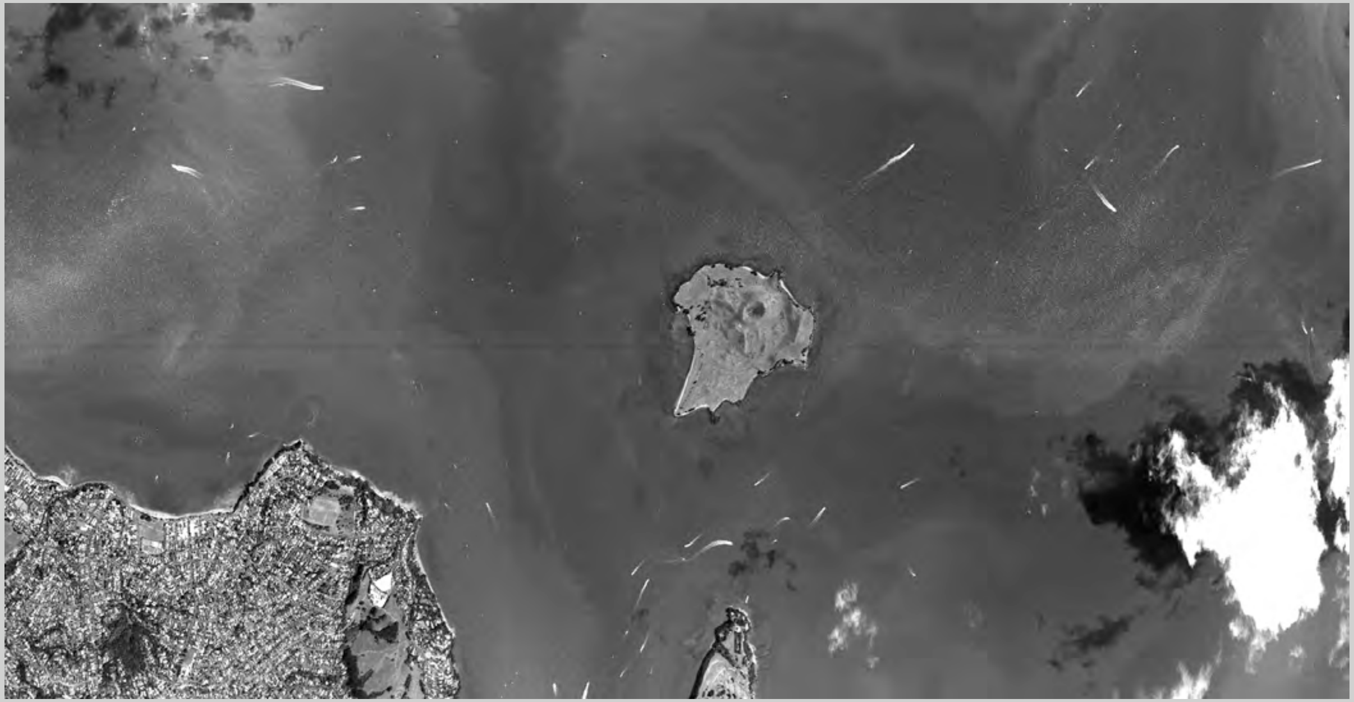
1 m GSD (*ground sample distance*) at
3,000 m height

3 lines: backward, nadir, forward

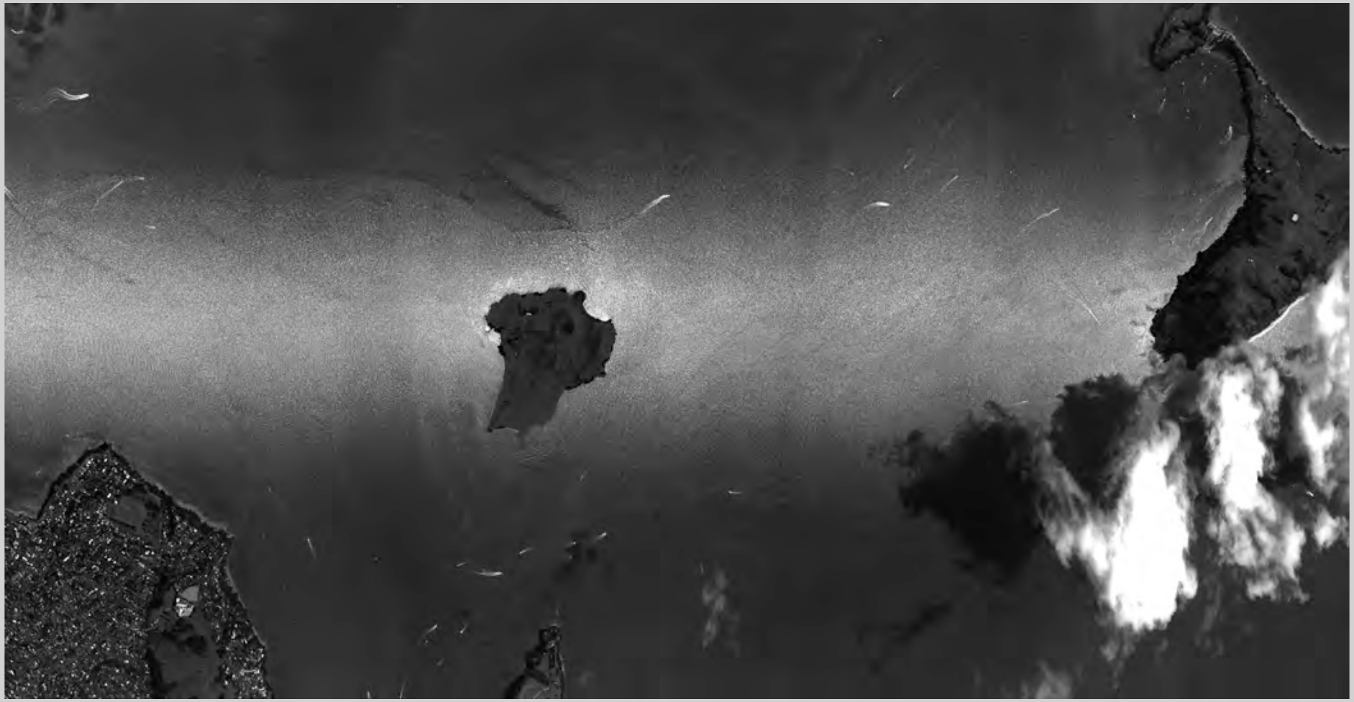
each line 5k pixel, grey values only

2001: WAAC flight campaign in Auckland

NZ Aerial Mapping Ltd



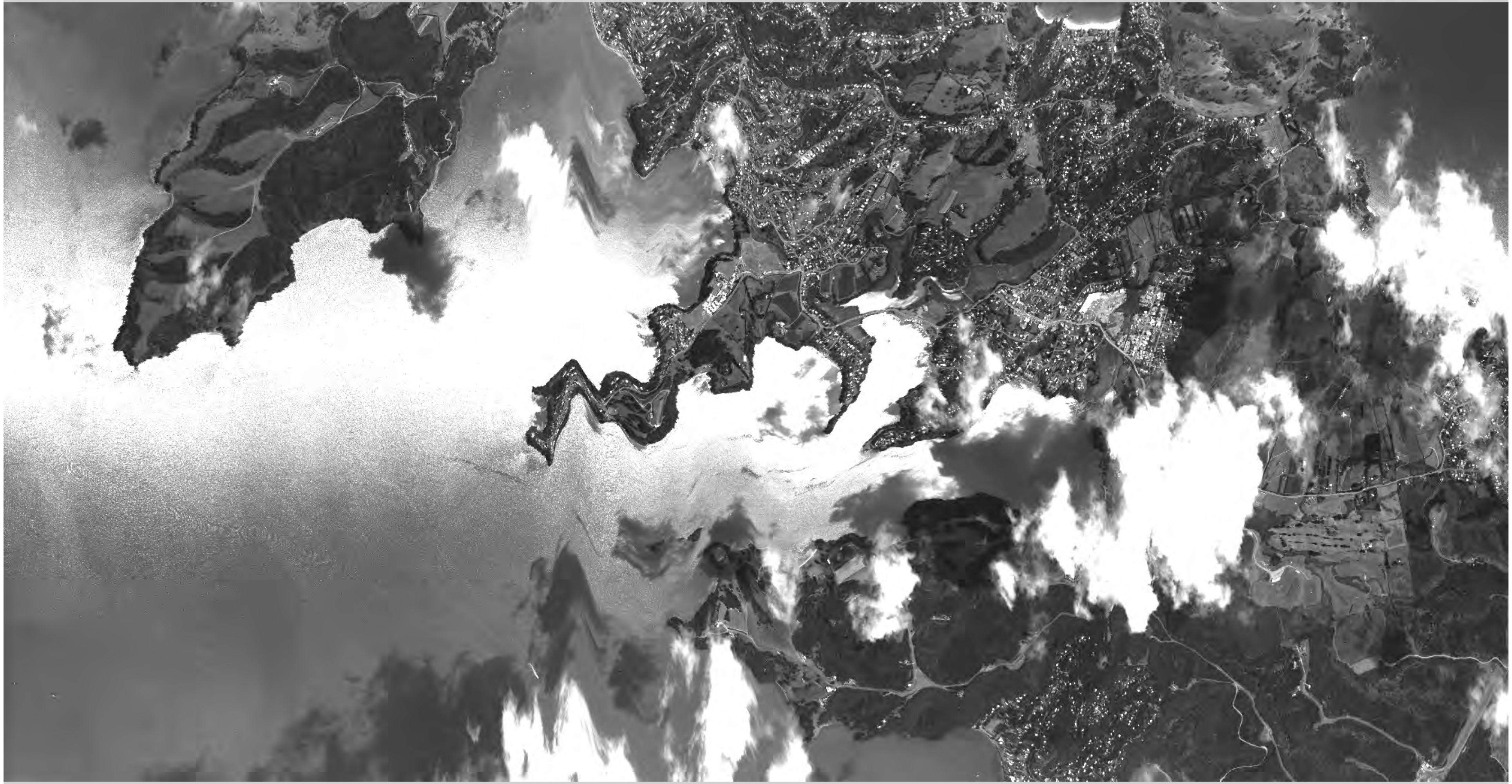
Nadir image



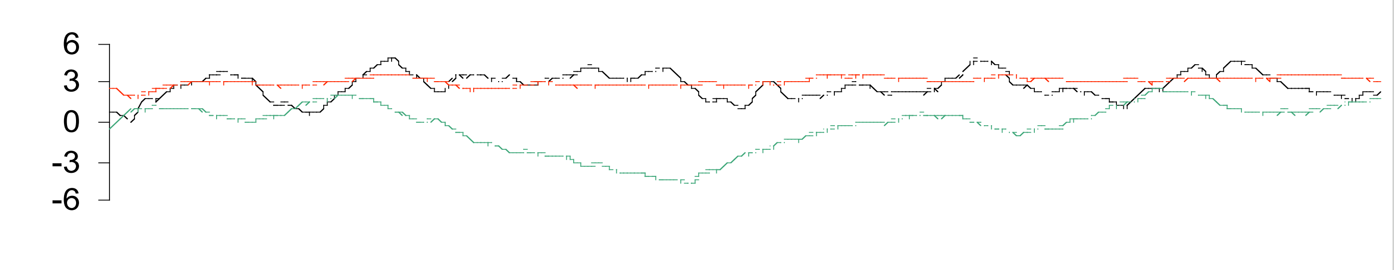
Backward image

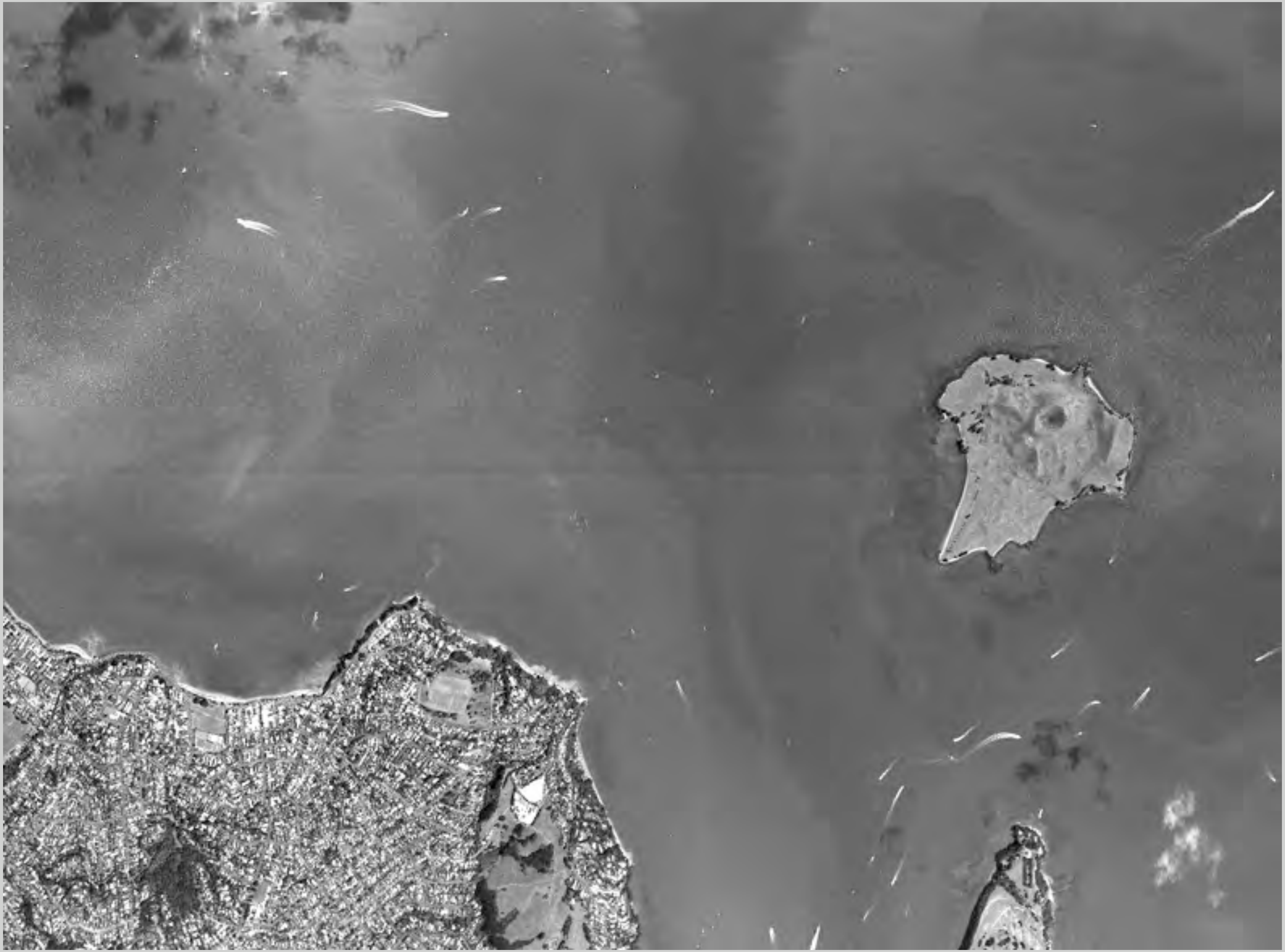
RK_RR

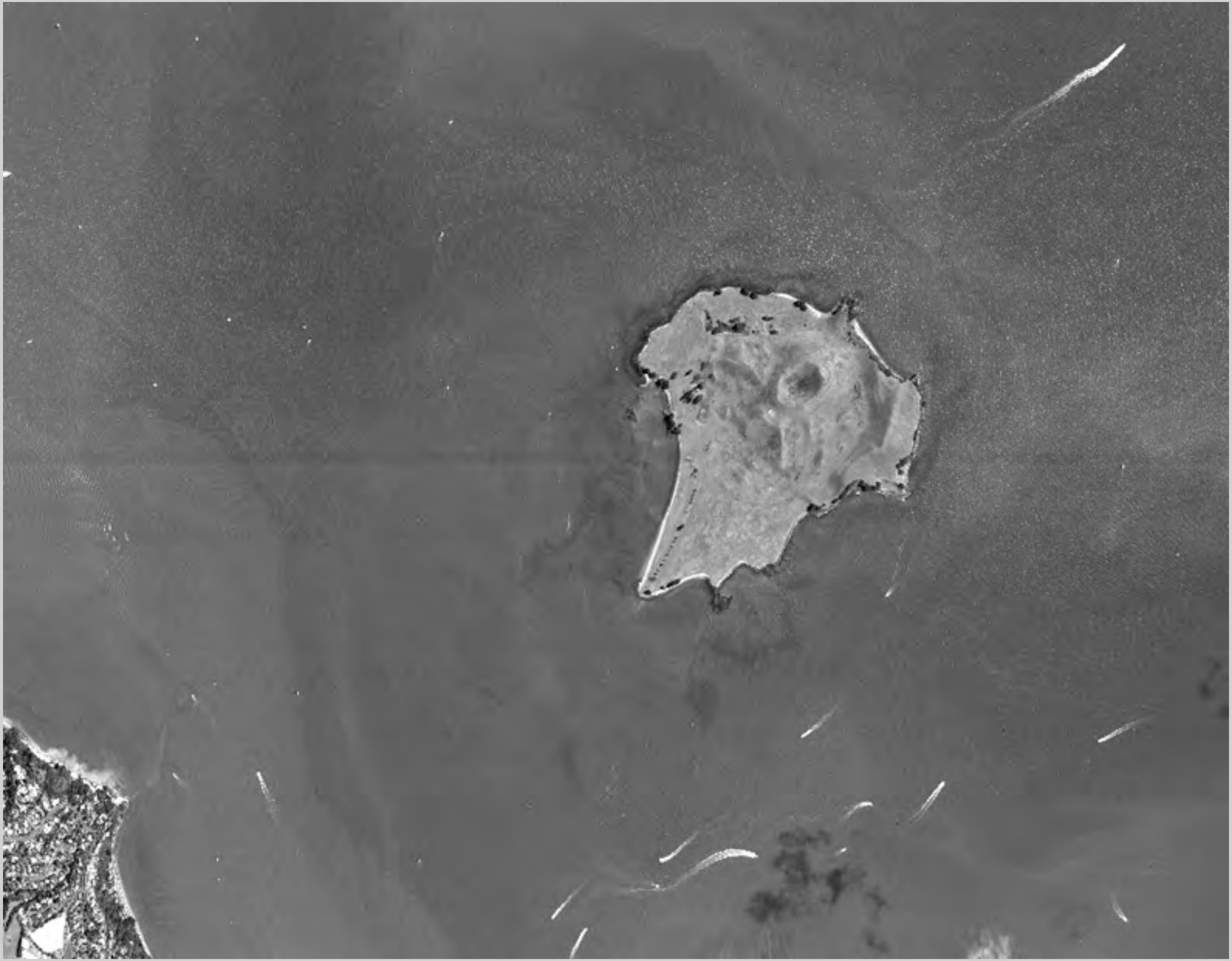
nadir channel without rectification



Inertial Measurement Unit (IMU)





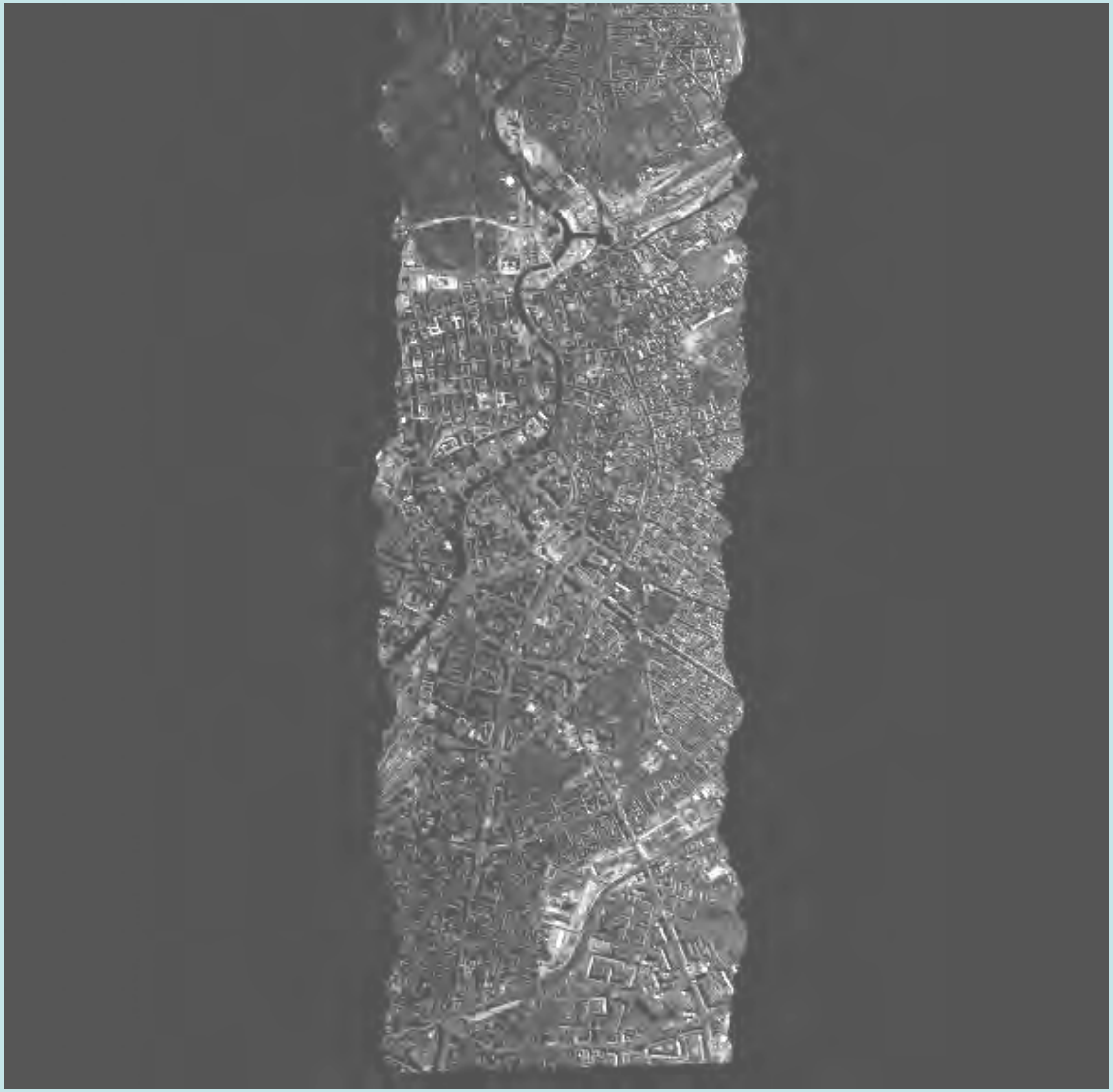


RK_RR

2000: ADS40 (airborne digital sensor)

- 3 panchromatic CCD lines each 2 x 12,000 pixels, staggered by 3.25 µm
- 4 multispectral CCD lines, each 12,000 pixels
- pixel size: 6.5 µm x 6.5 µm
- field of view (FoV) or swath angle: 64°
- focal length: 62.77 mm
- stereo angles: 14°, 28°, 42°

http://www.lh-systems.com/news/index.html



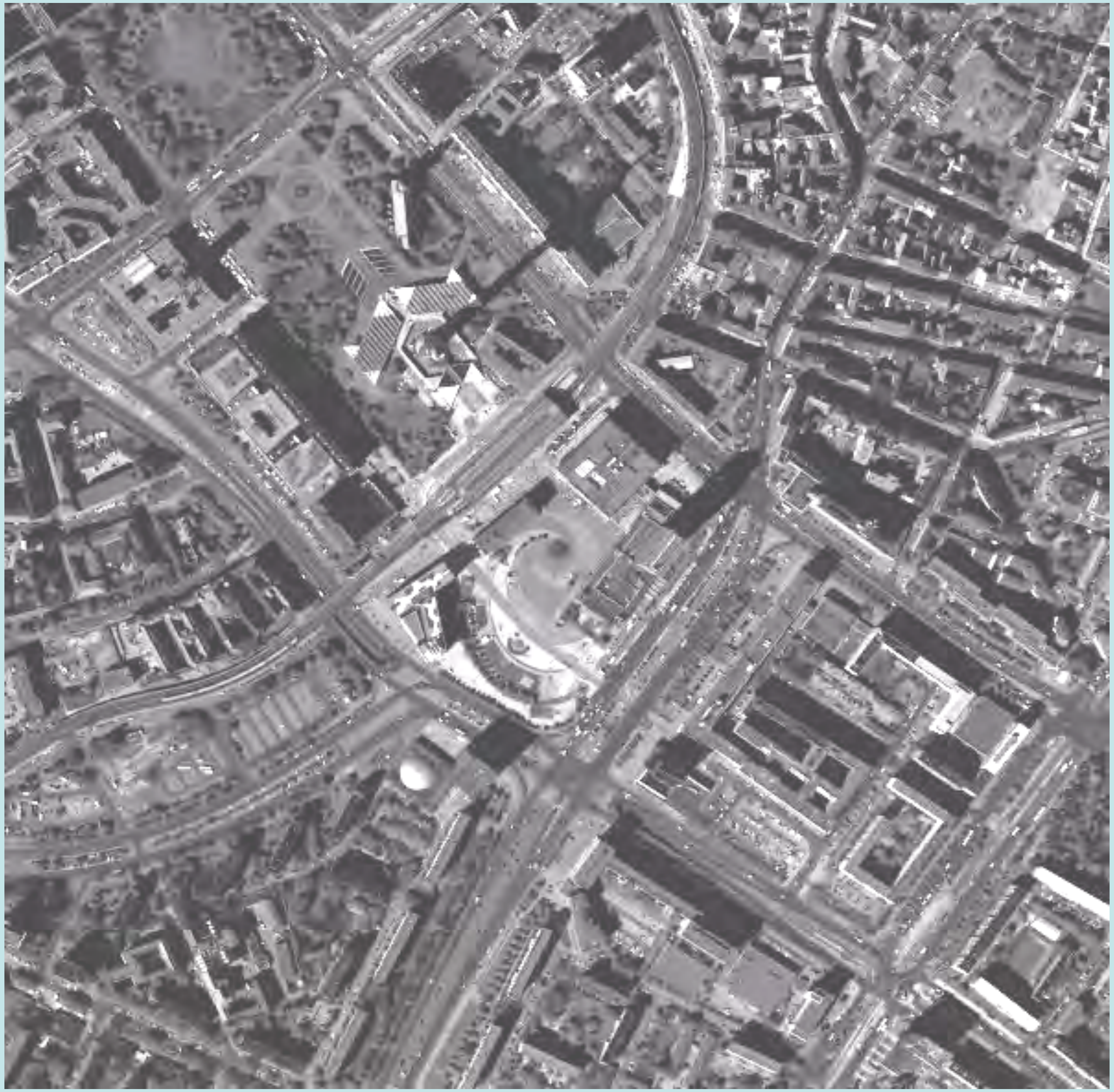
2000: ADS40

Berlin-Alexanderplatz

1:70,000

Elevation: 3,000 m

GSD ≈ 25 cm



Berlin-Alexanderplatz

1:500

End of 2004: CCD lines

Manufacturer	Model	Photopixel	Size [μm]
Atmel	TH7834	12,000	6.5×6.5
Atmel	customise	$2 \times 12{,}000$	6.5×6.5
EEV	CCD21-40	12,288	8×8
KODAK	KLI-10203	$3 \times 10{,}200$	7×7
KODAK	KLI-14403	$3 \times 14{,}204$	5×5
Fairchild Imaging	CCD194	12,000	10×8.5
SONY	ILX734K	$3 \times 10{,}500$	8×8

2005: Aerial photography, Remote Sensing

- navigation in realtime based on GPS
- flight management systems, IMUs
- camera systems are either
  - analog cameras
    - high precision optics
    - film of large format
    - automatic camera shutter
  - or digital sensors, such as
    - digital cameras
    - laser scanners
    - SAR (synthetic aperture radar)

Panoramic Imaging

Dwelling in the Fu-ch'un Mountains
Painted by Huang Kungwang during 1347-1350
Yuan Dynasty / handscroll / ink on paper, 33 x 639.9 cm

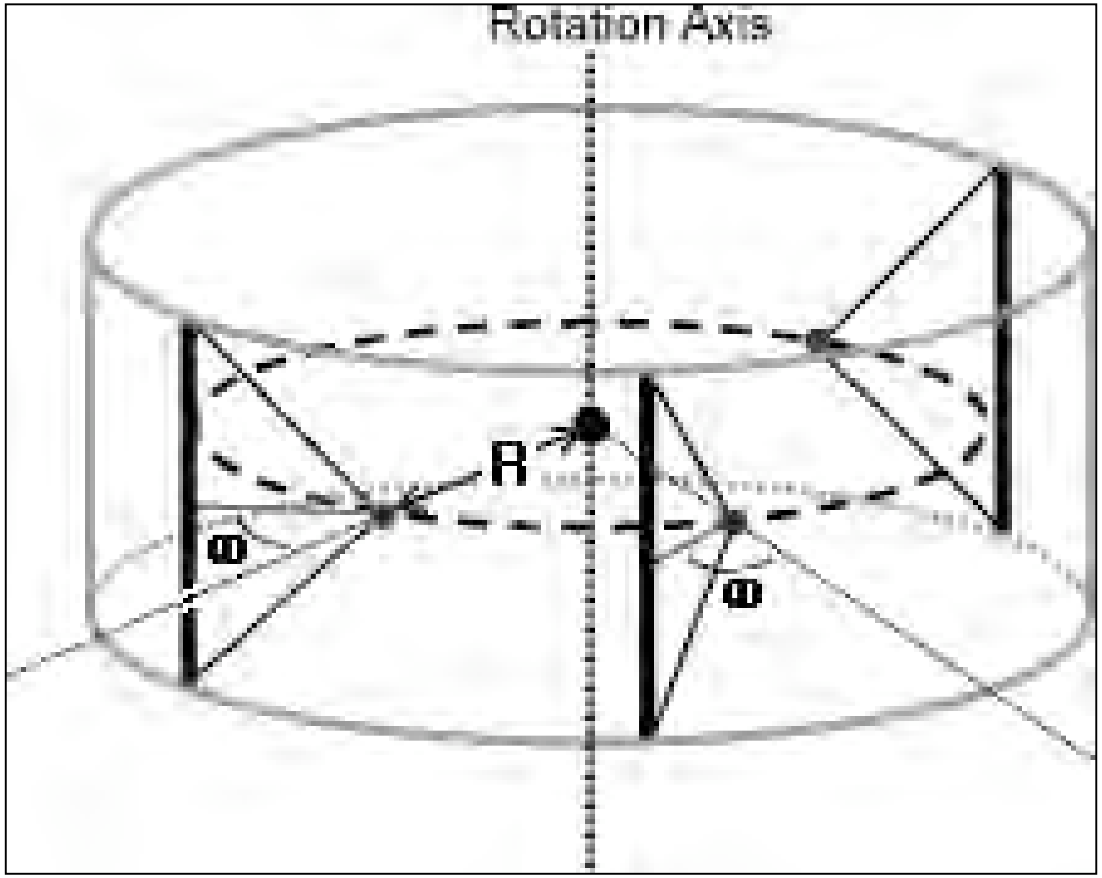
Digital Line Cameras for Panoramic Imaging

1995: Gendarmenmarkt, Berlin
panoramic image (5,184 x 9,425 pixel), WAAC on tripod

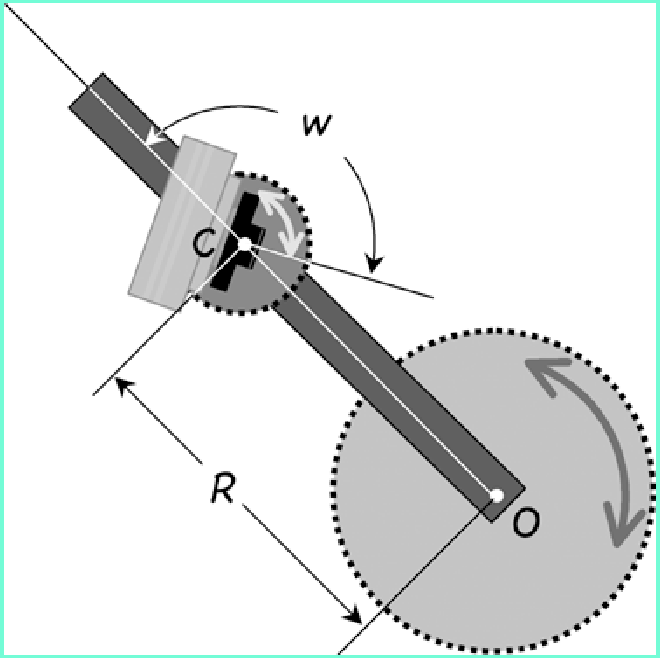
2001: 3.5 GByte on image, would be 4 m x 25 m at 72 pixels per inch

Detail of this panorama

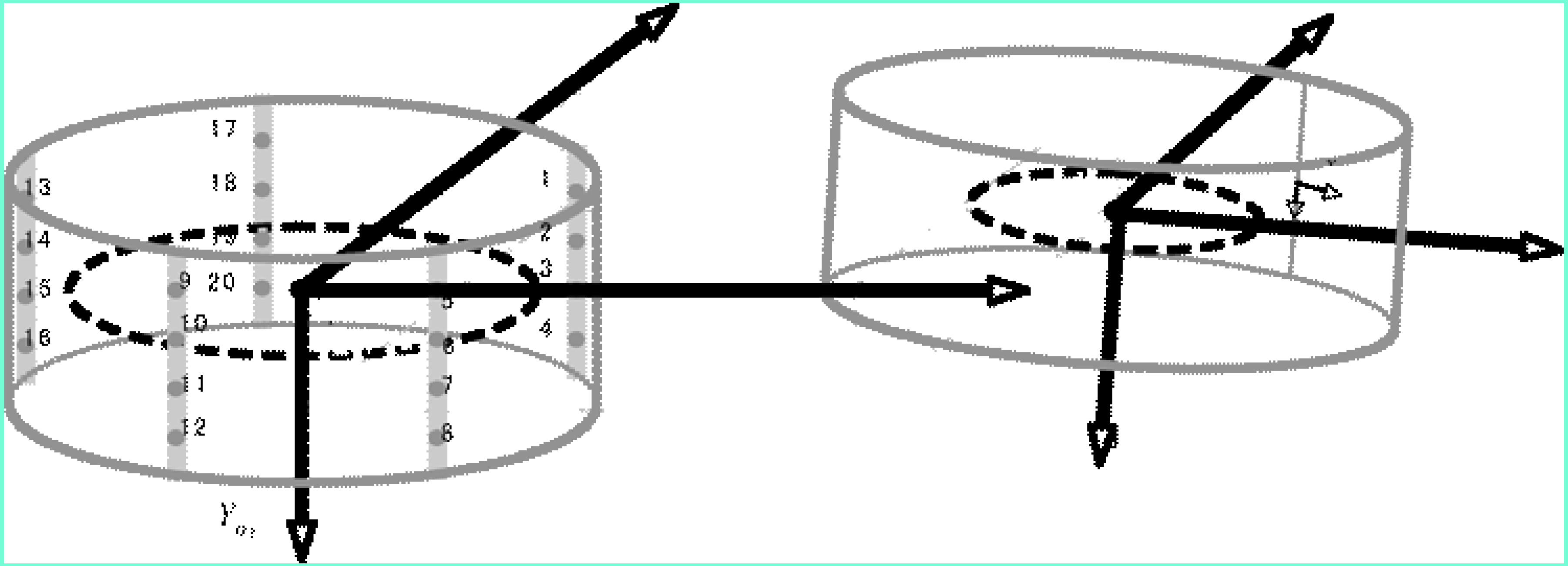
Digital Line Cameras for Stereo Panoramic Imaging



2001-2002:
rotating line camera (DLR),
design of stereo mode (CITR)



Epipolar Geometry

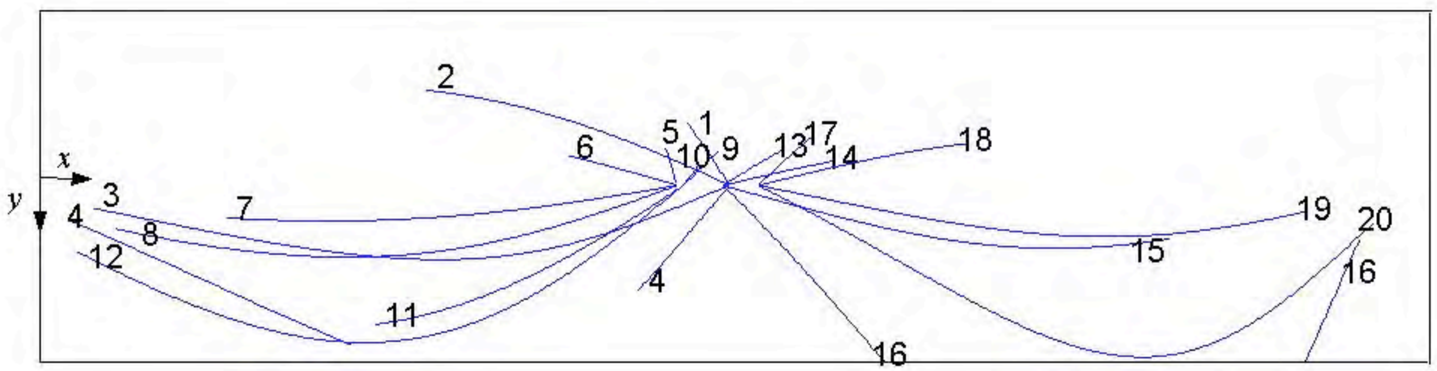


RK_RR

Coordinates of Corresponding Point

in second image (defining epipolar curves)

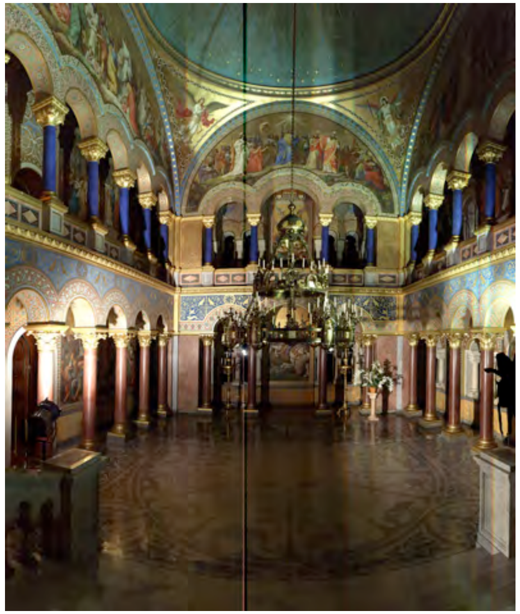
$$y_d = \frac{f_d Y}{X\,sin\left(\frac{2\pi x_d}{W_d} + \omega_d\right) + Z\,cos\left(\frac{2\pi x_d}{W_d} + \omega_d\right) - R_d\,cos\,\omega_d}$$



LASER SCANNER + PANORAMAS

range data

fusion of range data and color texture



DLR & CITR (K. Scheibe)

360 degree panorama

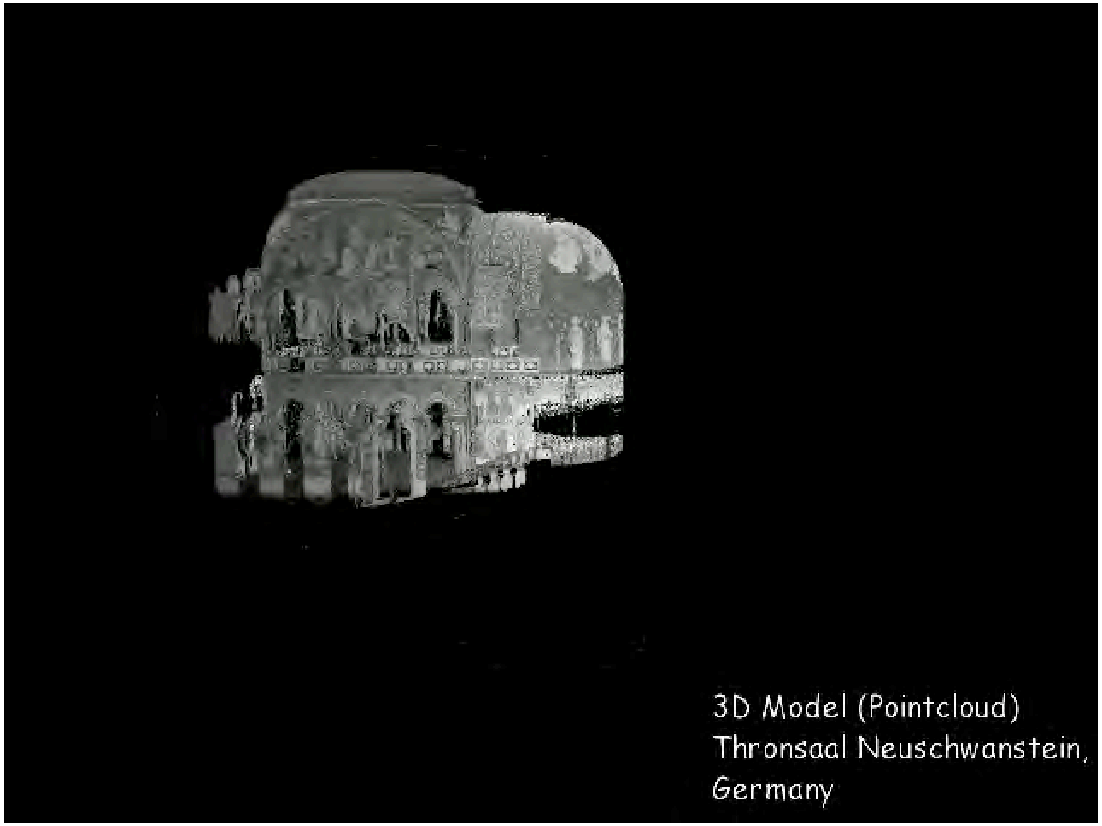


Image acquisition: LRF for range data, panorama camera for color

Calibration: view-dependent coordinate systems into local coordinates

Fusion: transformation of LRF and camera data into world coordinates

Preliminary result: a (colored) point cloud in world coordinates

Triangulation / Meshing: map 3D points into a *digital surface model* (DSM)

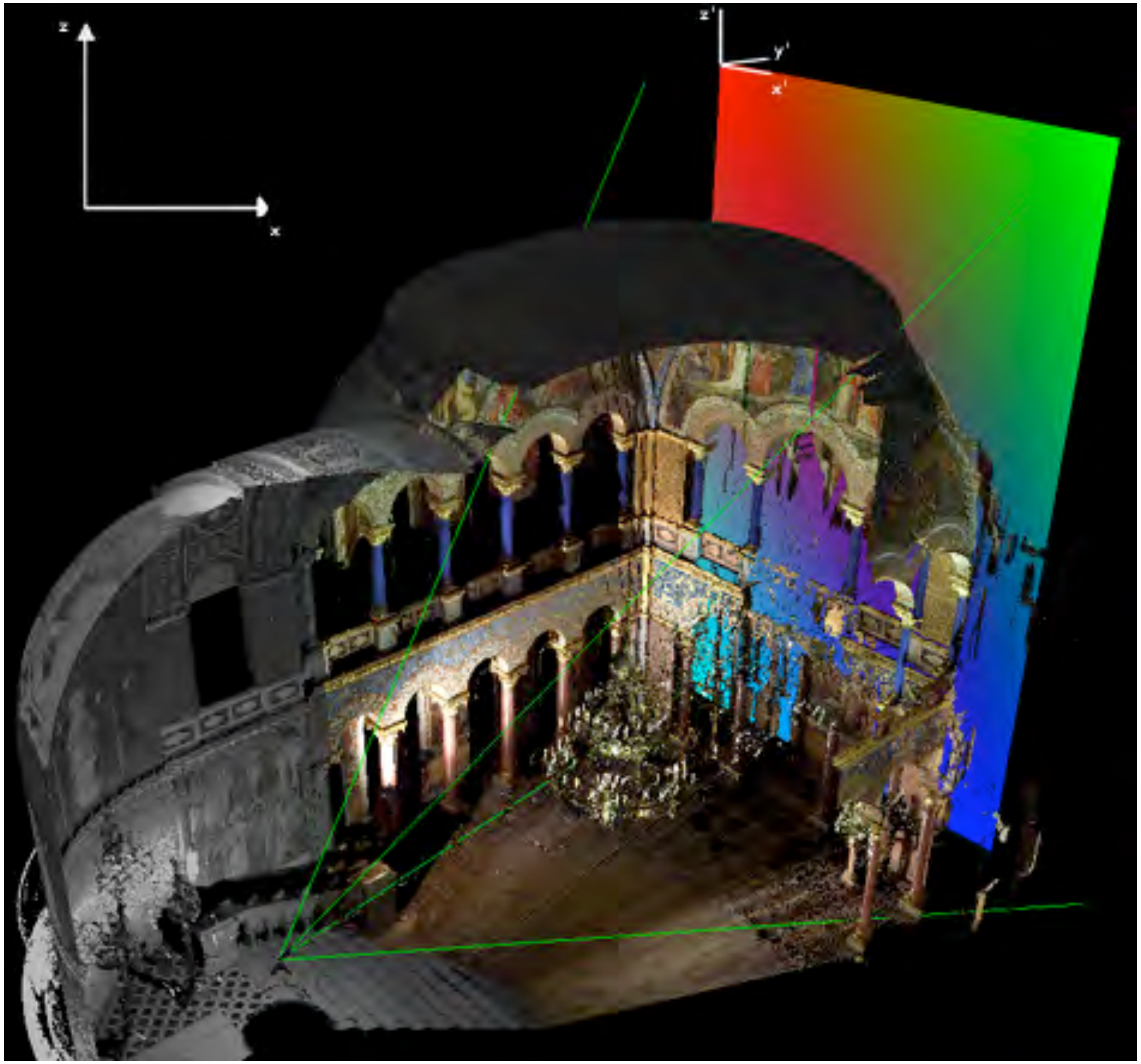
Optimization: reduce complexity of the DSM, eliminate noise

Texture mapping: map panoramic color data onto the DSM

Result: a colored DSM (within accuracy limitations)

Possible: 3D measurements, cuttings, orthophotos

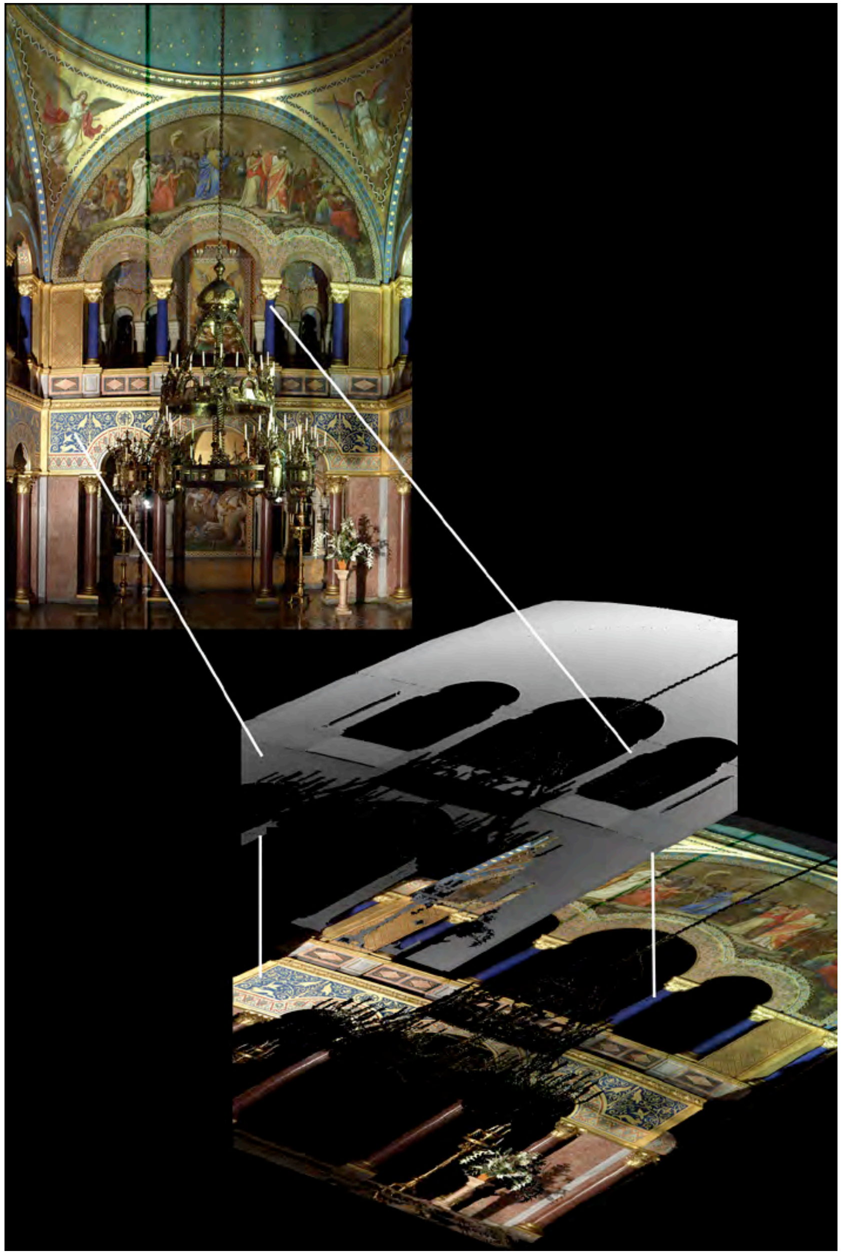
3D visualization (e.g., for virtual reality applications)



Orthoplane ("behind" colored DSM)

RK_RR

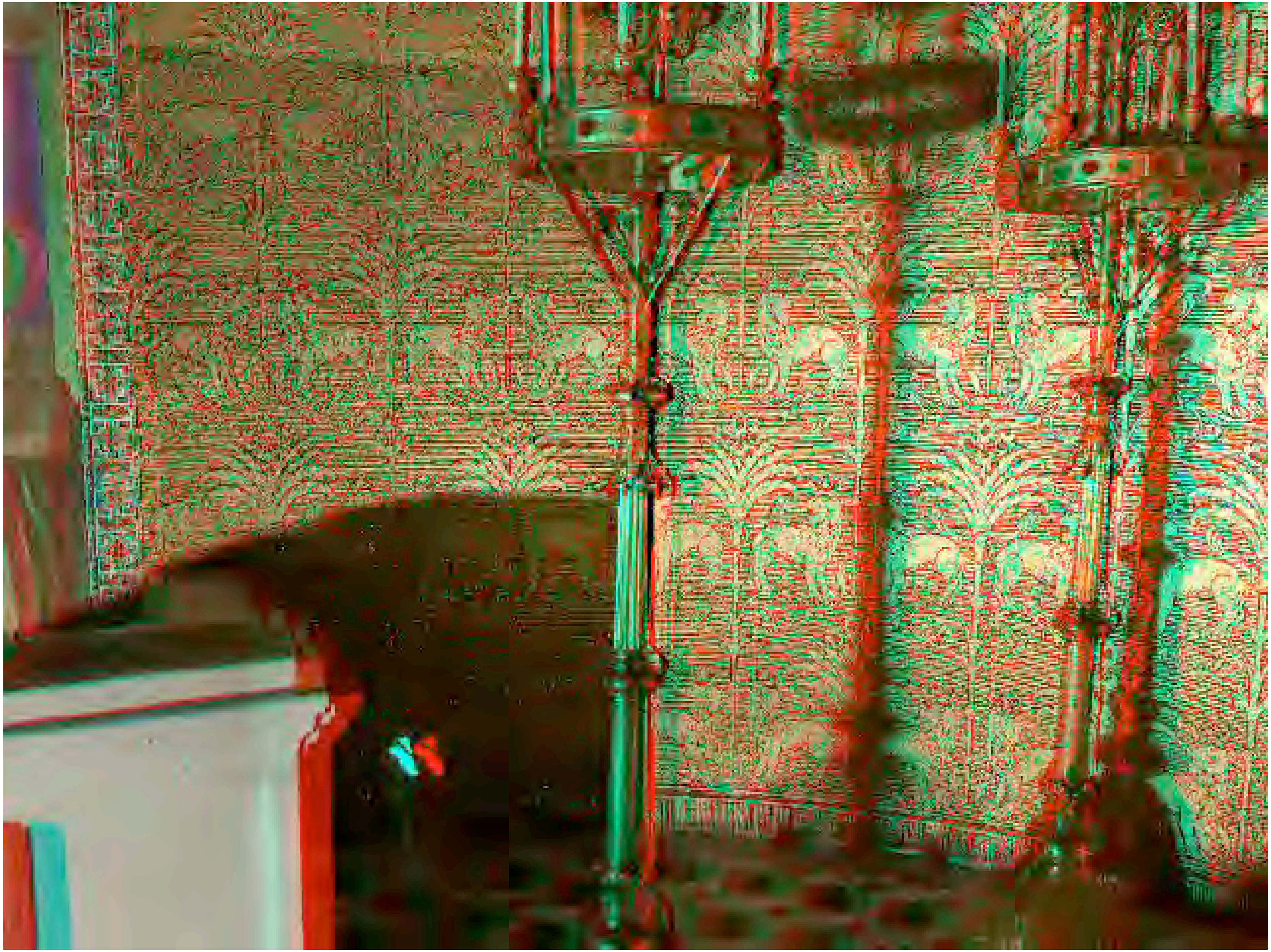
DLR & CITR (K. Scheibe)



1. Projection of DSM (visible triangles) into a defined orthoplane

2. Mapping of corresponding camera data onto this projected DSM

Orthophoto

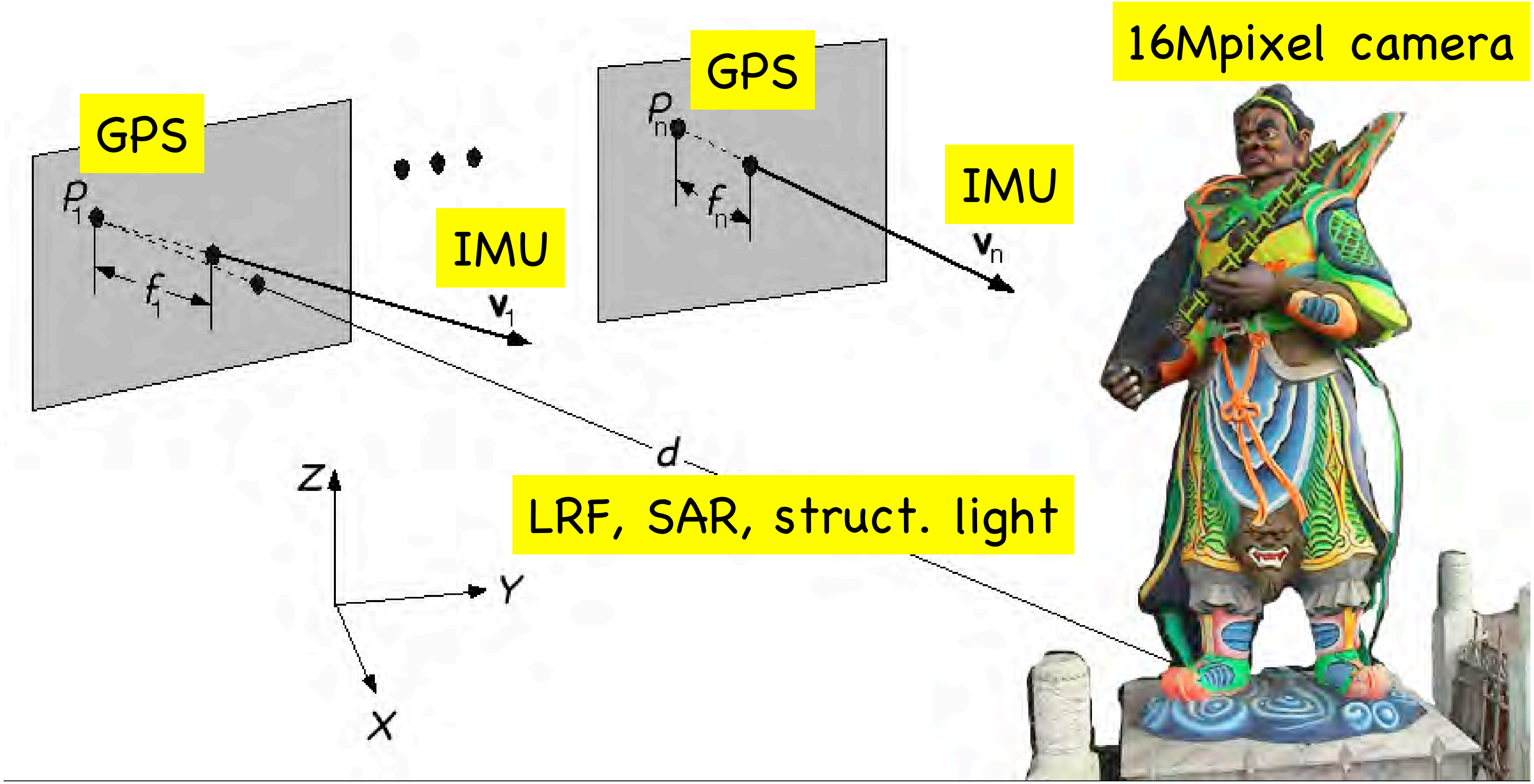


RK_RR

CONCLUSIONS

2005: we arrived at the "Multi-Sensor World"

cameras ------- for capturing textures
LRF,SAR,struct. Light, etc. ------- for distances
GPS or IMU ------- for position and orientation



Today's picture resolution asks for new approaches:

How to visualize a multi-GB picture on a screen?

Focused image analysis instead of full scans.

....

(image analysis and computer vision in the
"post-512x512-thumbnails imaging area")

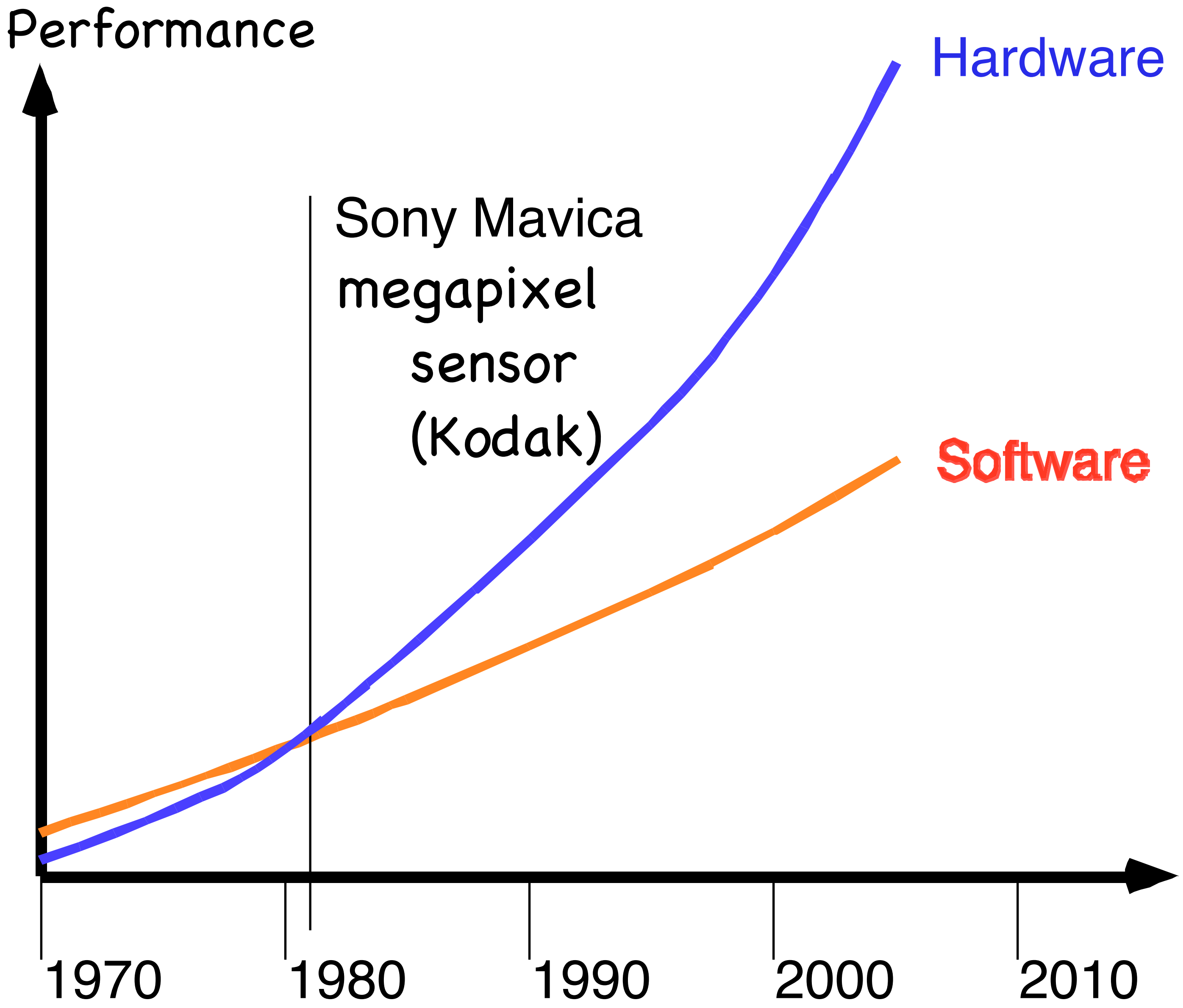
- **3D modeling in `traditional' photogrammetry, remote sensing and computer vision:**

  steady and solid progress over the years, where success in applications decides about the success of a method, not the academic challenge

- **Recently we experience a dramatic increase in available high-quality digital data, including LRF, SAR, GPS, IMU data:**

  These (new) tools will change the face of 3D modeling (paradigm shift) towards the use and the integration of these sensors, and towards unified methods in photogrammetry, remote sensing, and computer vision

- **Special sensors for modeling dynamic 3D shape?**


Performance
Hardware
Software
Sony Mavica
megapixel
sensor
(Kodak)
1970
1980
1990
2000
2010

The END